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REPORT #3

HUMAN SURVIVAL IN AIRCRAFT EMERGENCIES

By

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Aircraft and accident statistics have been provided by the FAA and the C.A.B. and interpreted by the writers for graphical presentation. Definition of the most adverse environments in which a human might survive have been abstracted from the FAA-Civil Aeromedical Research Institute work, and from NASA reports and the Flight Safety Foundation. In addition, a number of agencies and investigators have been consulted in an effort to gain in-depth information rapidly for this report. These contacts have thus far included:

1. NASA - Biotechnology and Human Research Division, Washington, D. C.

2. FAA - Mr. J. J. Swearingen, and Mr. A. H. Hasbrook, Civil Aeromedical Research Institute, Oklahoma City, Oklahoma.

3. FAA - Mr. J. J. Carroll, Supersonic Transport - Safety, Washington, D. C.

4. CAB - Mr. B. R. Allen and Mr. Hollowell, Bureau of Safety, Washington, D. C.

5. Mr. J. Lederer and Mr. Hallas, Flight Safety Foundation, Inc., Phoenix, Arizona

6. Mr. H. L. Mailander and Mr. R. G. McIntyre, Douglas Aircraft Company, Long Beach, California

7. Mr. P. B. Donaldson and Mr. B. A. Cosgrove, Boeing Aircraft Company, Seattle, Washington.

Additional contacts with these and other investigators are anticipated as the study continues in order to form a practical outline for survival concepts.

CONTENTS

FOREWORD

The purpose of this report is to provide the third part of a four-phase study. The overall study is to gather and evaluate data and methods to improve the probability of human survival in aircraft emergency conditions. The scope of this study is to include emergencies encountered by (1) commercial airlines, (2) general aviation aircraft, (3) helicopters, (4) government official transport aircraft, and (5) military aircraft.

This third report presents a description and anaylsis of some concepts that may improve the chance of human survival in an aircraft emergency where conditions would otherwise lead to certain fatality. This report further contains accident data and information from the previous report in order to maintain continuity.

1.0 INTRODUCTION

Design for human survival in aircraft emergencies may include four general and inter-dependent items.

The aircraft normal physical operating requirements.

The human physical limits.

The aircraft physical and economic operating environment.

The social impact of accident fatality.

This study dwells upon the aircraft requirements and the human physical limits in an effort to improve human survival in an aircraft accident. The operating environment and social impact is not treated within the scope of this study, except perhaps in the sense of accident statistical data.

The increased public trust in numbers of passengers per aircraft multiplies the need and importance of crash survival improvement. The multiplied ramifications of each death is felt throughout the society. The crash of a single Jumbo-Jet with 500 to 800 people aboard may cost $100,000,000 if hull loss, insurance suit claims and other involved personal losses and damages are included. Thus, it would appear that at considerably less than one percent of this cost an operator may wish to provide the means to prevent such a total loss and incorporate designs that would save all or most of the passengers if not the total aircraft.

General Influences on Aircraft Design For Safety Improvement

A few of the factors influencing design for accident survival are:

1. Size of aircraft (small single engine up to multi-engine jet)

2. Application (military, private, air carrier, executive, etc.)

3. Market demands (owners, passengers)

4. Cost (manufacture, operation, maintenance, weight, etc.)

5. Current use risk (insurance, reliability)

General Methods for Aircraft Safety Improvements

Concepts for the improvement of aircraft accident survival are divided into the categories of:

1. Internal fuselage improvements.

2. External fuselage recovery devices.

The first category contains occupant restraint, protection and evacuation, while the second category contains methods of aircraft kinetic energy reduction and fire suppression.

Internal Fuselage Improvements

Work at the Civil Aeromedical Research Institute (CARI) has been extensive in defining human body impact limits and injury levels.[2] This work, combined with that of the aircraft crash test data of the Flight Safety Foundation, Inc.[3], provides an insight into how aircraft interiors may be designed to improve changes for occupant survival. As outlined in a summary of notes by J. J. Carroll[4] and published reports by A. H. Hasbrook[7], the main factors for crash survival may be listed as:

1. Aircraft cockpit and cabin crashworthiness.
2. Secure seat tie-down and occupant restraint.
3. Removal of lethal objects and surfaces from the occupant-impact envelope.
4. Secure attachment, or repositioning of potential loose masses out of occupant path.
5. Suppression of smoke and fire.
6. Quick routes for evacuation.
7. Protection against external environment.

The definition of practical quantitative values to meet these requirements is difficult; in some instances uncertain, and in other instances disputed. Aircraft manufacturers have pointed out the need for accident survival criteria that is of rigorous argument, based on clear evidence, and of a quantitative nature for design and test.

A survey of persons and organizations active in the field of crash survival has revealed extensive study effort to improve occupant restraint and protection from dangerous interior objects. This effort to improve interiors is a result of findings from many accidents wherein the aircraft cabin has remained adequately intact while the occupants have died or were seriously injured because of smoke or fire, inadequate seat tie-down, seat belt restraint, or impact with local hard objects that had been placed too close for crash safety. Thus, interior safety improvements have received emphasis by various investigators because of the obvious need, and because of the relative ease of improving interior design.

External Fuselage Devices

General Aviation encounters about 70% of its fatalities in-flight, and for the most part, no provision exists that would allow these occupants to survive. The high-speed uncontrolled nature of in-flight accidents means that very little can be done to the internal cockpit and cabin structure to really improve the chances of survival at impact. Similar circumstances exist for commercial air carriers.

Before a significant in-flight emergency survival improvement can be anticipated, the velocity and impact angle conditions must be brought within the region of aircraft crashworthiness. This region is shown in Figure 1-1 as estimated from actual crash experiences and crash test data.

A crashworthy condition is one in which the cockpit and/or cabin areas remain reasonably intact, and thus, permits the well restrained and protected occupants to survive. In many cases, the only practical way to bring the aircraft velocity within the survivable crash region is to apply an external force to reduce kinetic energy. External recovery concepts are therefore required in addition to internal improvements if the majority of fatalities are to be prevented.

Figure 1-2 shows an approximate division of time available to effect recovery dependent upon the type of aircraft emergency. Except for cases of explosion, collision and some types of structural failures, sufficient time exists to initiate some form of emergency recovery procedures. In addition to the need for sufficient time to implement recovery, sufficient altitude is required in order to effectively decrease the velocity before impact. Recovery from altitudes as low as 500 ft. appear practical.

A chart listing various survival improvement concepts applicable to the various flight phases is shown in Figure 1-3. This chart itemizes each concept for improving accident survival and indicates which flight phase as well as the type of user that might be most practically benefited. Those currently considered to have practical potential are indicated in Figure 1-3 by a solid dot.

While saving life is of primary concern in an emergency, the actual cost of the aircraft has some bearing on whether or not a particular type of survival method can be applied and made economically practical. Figure 1-4 shows an estimate of the basic purchase price of an aircraft. This cost is given in dollars per pound versus empty weight and approximates a typically equipped aircraft. It is probable that added safety devices should not greatly exceed the dollar per pound values shown in Figure 1-4 since these values are currently established and accepted on the aviation market.

It is interesting to note that the general aviation piston engine aircraft show the cost per pound to rise in proportion to their weight. However, the cost per pound for jet aircraft remains relatively constant regardless of overall weight.

State-of-the-Art Concepts

Concepts for internal fuselage safety improvements such as seat-occupant restraint, and evacuation devices have become a matter of extensive study. The definition of internal concepts therefore is concerned more with defining an improved criteria for present methods. The boundary of velocity and impact angle at which internal fuselage improvements could no longer be considered effective is shown by the shaded part of Figure 1-1. Within this shaded interface the aircraft structure can no longer remain intact and total destruction commences. (The graph as presented assumes a level impact surface without aircraft yaw.) Statistics show a great percentage of fatalities to occur in the realm of total aircraft destruction. Thus, concepts are definitely needed that can be applied externally to bring the aircraft velocity and flight angle into the survivable boundary. (An alternate scheme would be to raise the crashworthiness boundary by strengthened structure and interior; however, this proves to require very large weight penalties compared to external recovery devices.)

The following approximate the survivable crash conditions found in some survivable transport crashes investigated by Av-CIR:[7]

1. 150 knot impact speed

2. 15° nose down (pitch) angle

3. 30° yaw angle to either side of the longitudinal axis of the aircraft

4. A resultant crash force angle within an arc extending from 15° above, to 45° below the longitudinal aircraft axis (in the vertical plane and parallel to the longitudinal axis).

5. A roll angle of 30° to either side

6. Impact against, and a deceleration on, a reasonably level terrain having the general density of plowed ground.

Concepts to bring an aircraft within the survivable zone incorporate methods to decrease fuselage kinetic energy. As seen by the chart of Figure 1-3, the methods include such devices as descent parachutes, retro-rockets, drogues and crash barriers. Closer examination of Figure 1-3 reveals that the concepts for survival fall into those useful for take-off and landing, and those useful for in-flight. The exception is seat and capsule ejection systems found useful by the military for escape in all modes of aircraft operations. A simple ejection seat system might be found useful in small low speed aircraft. However, most civilian applications for ejection seats could not be effectively installed and would not out-weigh the advantages that could be accomplished by recovery of an intact aircraft/fuselage.

Generally, a combination of different recovery concepts is required to achieve survival over the entire flight envelope. For example, the small quantity of special government official aircraft and the critical value of the occupants might permit combined concepts such as deceleration retro-rockets and descent parachutes to be applied to an entire aircraft fuselage to effect recovery. This same concept applied to commercial air carrier transports would require much closer study since the economics are more complicated and marginal. Thus, even though the accident survival chances would be improved in both cases, the relative economic utility and impact would be much different.

The use of only a descent parachute to recover the entire aircraft becomes more practical as the size of the aircraft decreases. For this reason, most of the general aviation aircraft could incorporate an emergency descent parachute recovery system at a weight increase of less than 3 percent. Where sufficient warning exists the number of in-flight phase fatalities as well as the number of aircraft destroyed subsequent to in-flight emergencies could be reduced by as much as 80 percent.

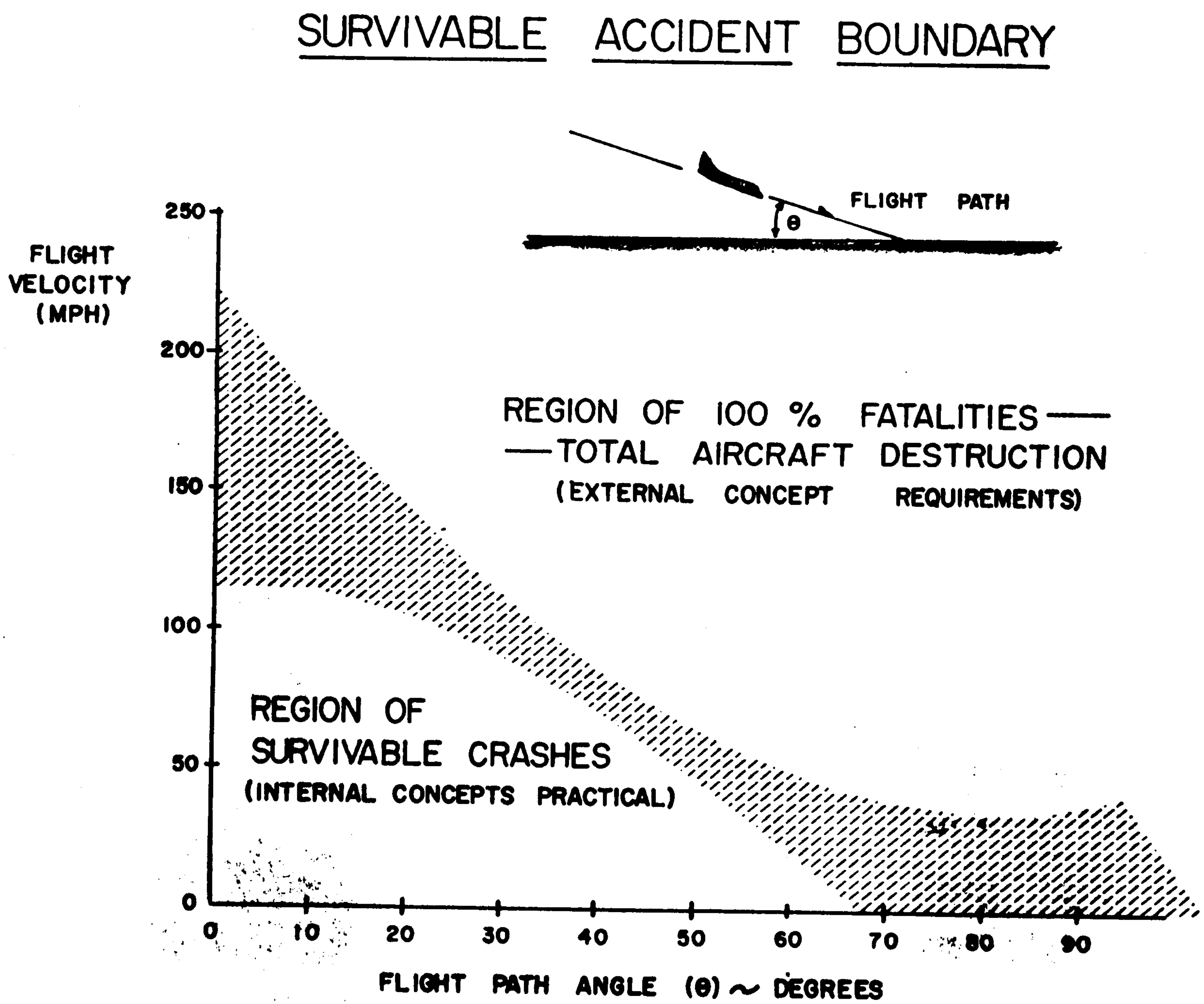
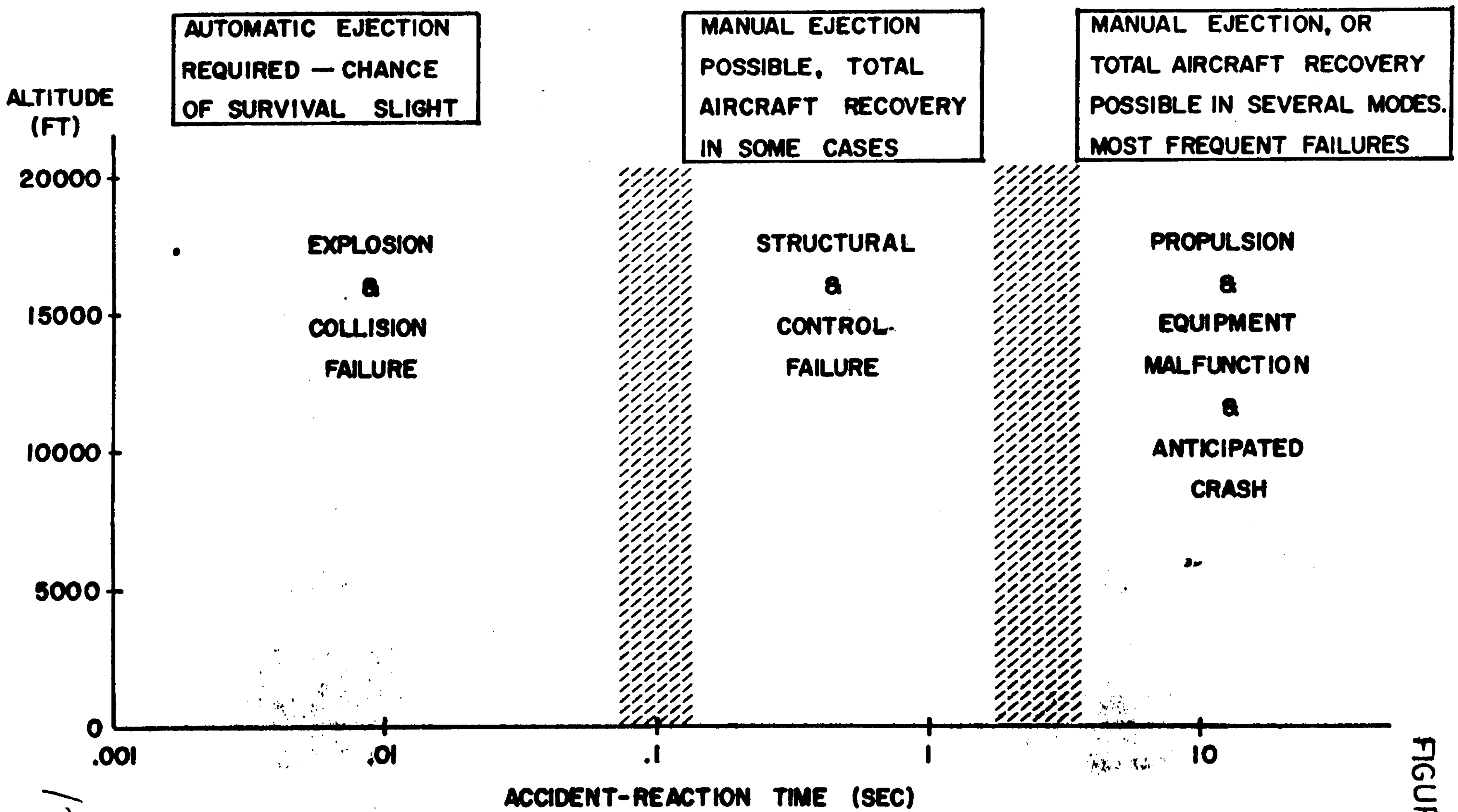


FIGURE 1-1

FIGURE 1-1

ACCIDENT SURVIVAL REGIMES



1-8

FIGURE 1-2

FIGURE 1-

ACCIDENT SURVIVAL METHOD CHART

SURVIVAL MODE	TAKE-OFF					IN-FLIGHT					LANDING				
	GROUND RUN UP TO 50 FT. ALTITUDE					CLIMB, CRUISE DESCENT & APPROACH					BELOW 50 ft ALTITUDE TO LANDING ROLL				
	P	C	M	H	E	P	C	M	H	E	P	C	M	H	E
DROGUE PARACHUTE	●	○			○						●	●	●		●
DESCENT PARACHUTE (Appendage severance optional)						●	●		●	●					
RETRO-ROCKETS (near GRD) (Appendage severance optional)						○	●		●	●					
RETRO + STABILIZER CHUTE (Appendage severance optional)					○	○	●		●	●					☒
SEAT EJECTION			●					●					●		
CAPSULE EJECTION			●		●			●		●			●		●
PERSONAL PARACHUTES						●	○								
COMMON EXIT EJECTOR (individual parachutes or pod)							●			●					
FAST FUEL DUMP						☒	○	☒	☒	●					
FUSELAGE ATTENUATORS (External devices)		○		○	●							○		○	●
CRASH BARRIERS (At airports only)	○	○	●		○						☒	○	●		○
INTERIOR CRASH PROOFING (Seats, floor, surfaces, etc.)	●	●	○	●	●						●	●	○	●	●
CRASH CAPSULES				☒	●									☒	●

☒ SURVIVAL METHOD POSSIBLE BUT WITH PRACTICAL RESERVATION

○ SURVIVAL METHOD WITH SIGNIFICANT SURVIVAL IMPROVEMENT

● SURVIVAL METHOD IMPROVEMENT WITHIN PRACTICAL COST

P = PRIVATE GENERAL AVIATION

C = COMMERCIAL AIR CARRIER

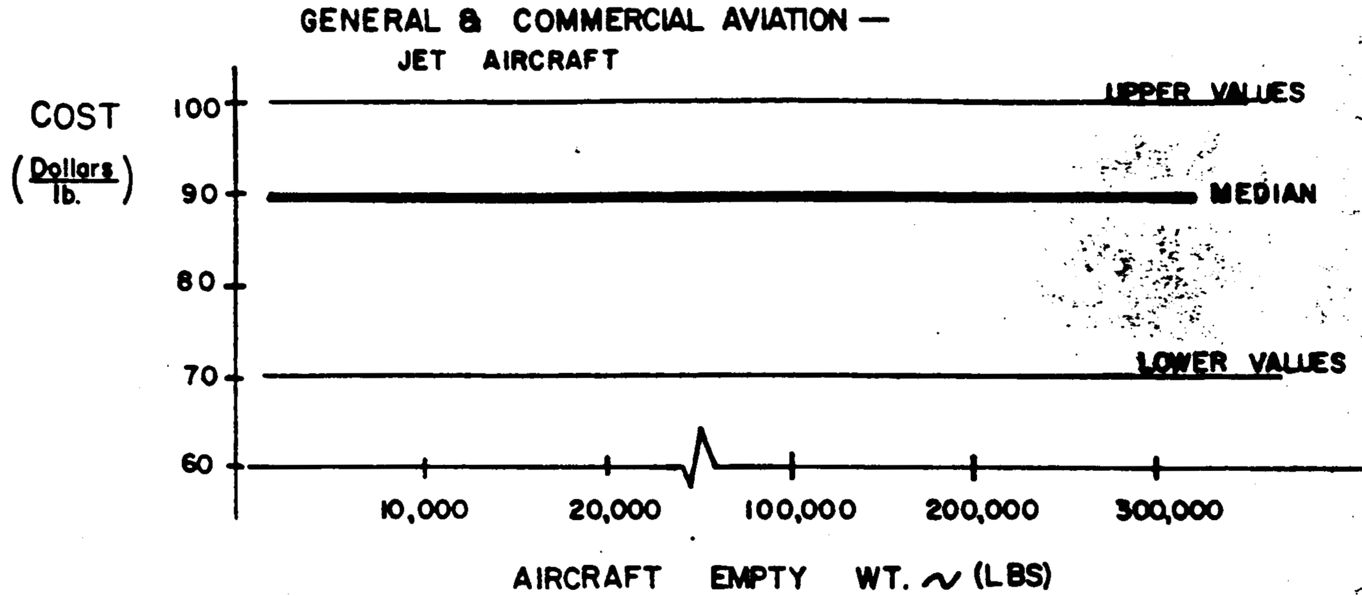
M = MILITARY AIRCRAFT

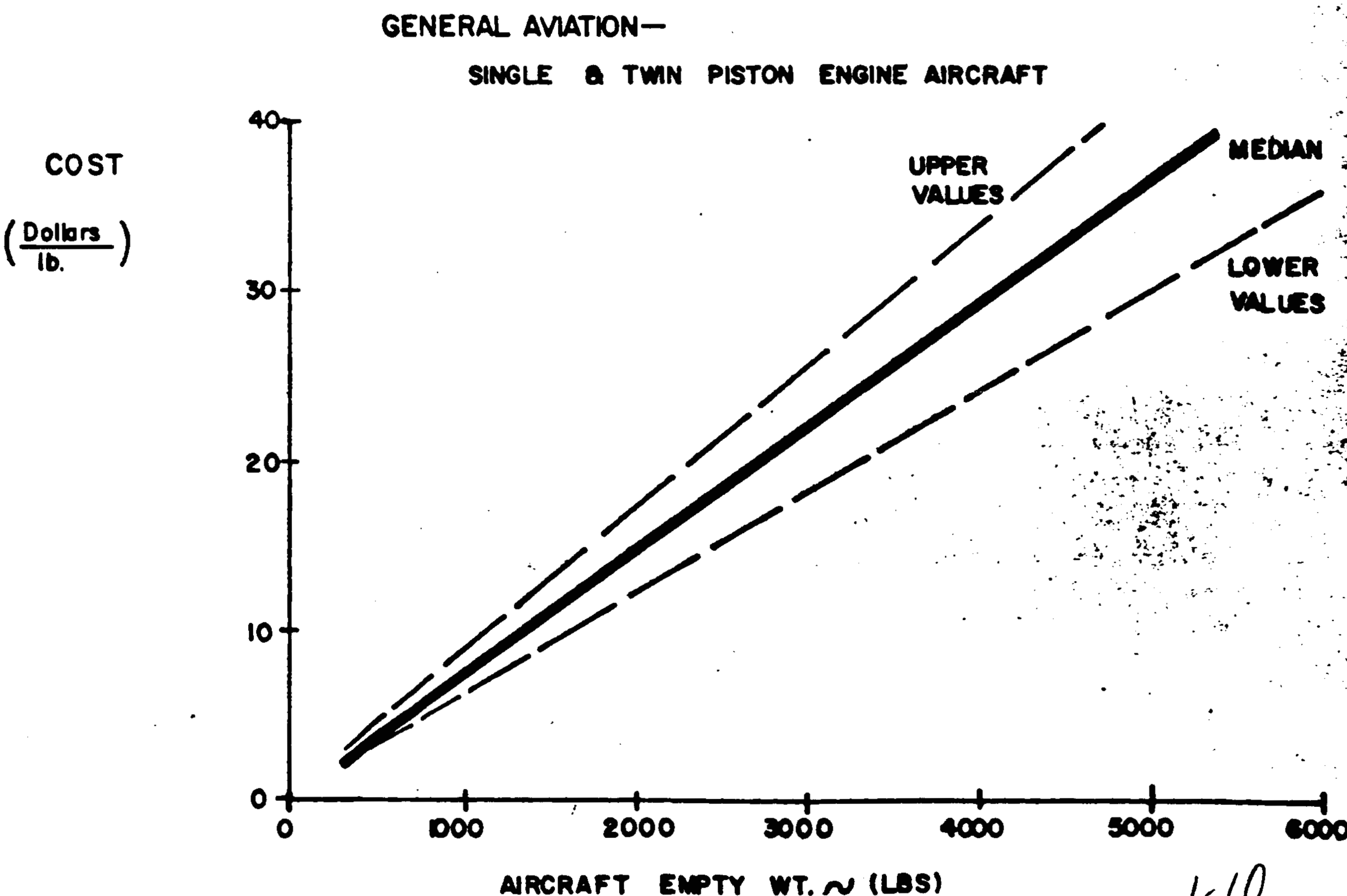
H = HELICOPTERS

E = EXECUTIVE OFFICIALS

FIGURE 1-4

TYPICAL AIRCRAFT COST FOR YEAR 1966





2.0 INTERNAL TO FUSELAGE SURVIVAL IMPROVEMENT METHODS

A survivable aircraft accident is classified as a crash in which the cockpit and cabin remain relatively whole after impact even though a post-impact fire might completely destroy the plane.

The improvement of occupant safety in an aircraft emergency can be accomplished by devices external to the aircraft, as well as by design changes internal to the aircraft cabin. Internal design improvements are the most direct and immediately possible. Most of these improvements apply directly to internal occupant furnishings such as seats, restraint devices, toxic gas protection, etc., and therefore do not affect primary aircraft design and manufacture.

The improvement of occupant safety can most easily start by a careful study of internal cabin factors. The primary factors to consider for physiological protection internal to the cabin are:

1. Occupant restraint.
2. Seat attachment and emergency design features.
3. Smoke, heat, vision protection.
4. Evacuation assistance devices.

A great deal of study and research has already been accomplished in human physiology that is useful in the areas listed above. Preliminary information therefore exists to initiate specific improvements and explore prototype designs.

SEAT DESIGN

One of the most immediate courses to improved occupant safety is in the direction of aircraft seat design. Seats may be improved by giving design attention to the following items:

1. Minimize seat mass, particularly in upper seat back.
2. Avoid hard structure exposed to body impact.
3. Use ductile energy absorbing materials for primary structure.

4. Provide enfolding seat structure for occupant protection.

5. Provide crushable, impact attenuation surfaces.

6. Increase floor attachment strength.

7. Improve lap belt latch against accidental release.

8. Provide emergency use upper torso and head restraints.

9. Build in seat safety aids (toxic gas, heat, vision, decompression).

10. Extend upper seat back above head level for head protection.

The integral parts of a passenger seat tie-down system are the lap belt, lap belt anchorage, seat portions which carry safety belt loads, seat anchorages and the floor structure. Frequently, improvement is needed in the design and strength of these components. (Belt releases are often very susceptible to accidental release.) The use of ductile structures is important since this would allow deformations precluding complete seat failure.

Whenever practical, passenger seats should only be attached to one surface such as the cabin floor. Differing surface attach points such as wall-floor structure often imposes torsion on the seat ties and results in greater deformation damage.

Some transport aircraft have seats which place the passengers in a backward facing position. With an aft-facing seat in a crash situation and present waist type seat belts, the occupant cg is situated at a point higher than the c.g. of an occupant in a forward-facing seat. Higher moments would be generated by the higher c.g. of the aft-facing seat. For aft-facing seats a weight penalty may be expected in the floor structure and attachments in order to withstand the higher moment forces. However, the improved full body restraint on forward-facing seats would result in similar higher c. g. conditions as that for an aft-facing seat.

In current seats, particularly in general aviation aircraft, conditions exist for injury and loss of life due to impact with rigid structure. It is known that 70% to 80% of all general aviation injuries and deaths in crash decelerations are from face or head injuries, or both, caused by body flailing. Improved design incorporating delethalization of the cabin area as well as upper torso restraint would certainly decrease the injury index in survivable crashes.

Hard construction should not be used in areas of likely occupant contact during impact. Areas where face impact might occur should be well padded with a slow return material. Seat backs and serving trays should be made of a material that would deform and contour itself to the head and face at loads less than 30 g (reference Figure 9-4). Seat arm lethal characteristics should be eliminated.

C.A.R.I. Report 62-13 points out the need for adequate seat tie-down. The requirement for a 2 g upward strength based on the seat and occupant(s) weight alone, results in a vertical tie-down strength of less than 1000 pounds. Dynamic force moments, and the legs of the passengers seated behind a given seat may impose a lifting force of 2 to 5 times greater magnitude than the tie-down strength of the seat in question. Thus, the seat attachments more easily fracture and the seat/occupant body becomes a lethal missile. Here again, the needs for stronger attachments and sufficient padding in areas of bodily contact are indicated.

Figure 2-2 shows motion paths of 5th and 95th percentile subjects accelerated forward over a tight safety belt. The subjects were displaced by a 1 g force so the measurements presented must be considered as minimum strike distances. The tangential velocity of the head during these tests exceeded 12 ft./sec. In actual crash conditions larger magnitudes of body movement would be expected since impact forces would most likely be greater than 1 g and the passenger's seat belts would probably be more loosely fastened.

Belts, Shoulder Harness

Deceleration tests have demonstrated that a well restrained man in good condition can tolerate crash forces as high as 35 g's. A force of this magnitude would probably destroy the conventional aircraft cockpit and cabin. This does indicate however that people should survive impacts where the structures remain primarily intact since such a crash would be within human tolerance.

Proper bodily support is required for survival under crash conditions.

Shoulder harnesses are essential to prevent excessive head travel and velocity build up. With a harness, it is estimated that a person could live through a 30 to 50 g deceleration transient. The use of the shoulder type safety belt would save most of those who are at present killed or injured from trauma to the head and face only, and perhaps many others.[4] Thus, development of a simple shoulder-seat restraint would be worthwhile.

Energy Absorbing Seat Development

A light-weight, high-strength seat which is designed to offer maximum occupant comfort is shown in Figure 2-1. Energy absorption is provided by mechanical attenuators in forward and vertical loadings.

The seat is designed for the following dynamic load conditions: 20 g vertical, 20 g fore and aft within a 30° arc to either side and 10 g lateral. This seat strength is based upon an occupant weight of 225 pounds.

A combination restraint harness and multi-directional locking inertia reels are provided. The restraint harness is designed to prevent submarining of the seat occupant upon experiencing severe forward crash decelerations. A single point quick disconnect fitting has been designed and included which allows fast harness release.

Seat weight is kept to a minimum through the use of aluminum honeycomb construction in all structural panels. Less cushions and mounting tracks, the seat weighs approximately 35 pounds.

Structure

The floor structure needs to be one of the strongest parts of the fuselage for adequate seat attachment.

The overhead rack structures of the commercial cabin should be designed in order to remove their lethal characteristics. Brittle, or hard, materials should not be used in cabin interior construction where occupant contact is likely.

The lower fuselage structure should be designed in order to sufficiently resist collapse under a wheels-up landing so that the cabin floor and seat attachments would not be destroyed.

The design and use of internal fuselage crash capsules to inclose personnel may be a feasible solution to impact attenuation for some executive aircraft. (Reference Figure 2-3). Such crash capsules could be installed in executive helicopters and transports. They would be constructed from materials possessing high strength to weight ratios and large factors of safety so as to remain intact upon impact. Forces the human body would feel could be reduced by external attenuators and deformable seat structures inside of the capsule. The capsule must serve as a complete inter-fuselage structure with all support systems common to the conventional aircraft cabin.

Evacuation

In a survivable accident, statistics indicate that post-impact fire is the most serious condition that passengers and crew must cope with in order that they might survive. There have been over 150 accidents involving U. S. air carriers that were caused by or resulted in fire during the period, 1955-1964. Only 57% of the 4559 occupants in these crashes survived. Of the 1955 fatalities, 297 or 15% were due to fire. These statistics certainly point out the need for more fire and smoke protective devices for the occupants. Human tolerances to temperature are partly outlined by Figure 9-5. Current FAA and industry work on improved fuel cells and thickened type fuels are aimed at reducing the fire hazard.

Emergency lighting in the cabin and cockpit sections should be fail-safe; that is, the lighting should be made to function automatically in a survivable crash condition.

Three primary objectives are being pursued in order that more people might evacuate an aircraft crash:

1. After impact, there is the need to increase survival time prior to evacuation by providing maximum protection from fire and fumes for passengers and crew.

2. Survivor mobility to exits must be increased.

3. Occupant movement from the craft to ground must be made faster, easier, and safer.

Since late in 1961, the FAA has required that emergency evacuation demonstration tests be conducted by all air carriers for aircraft with a seating capacity of 44 or more. These tests indicate problems encountered in emergency escape. The development of a door-mounted inflatable slide has resulted from the demonstration evacuation program. These slides are inflated by simply pulling a release cable. Tests have shown that the slides can be made ready for the first evacuee within 10 seconds of the start of evacuation.

S. R. Mohler and J. J. Swearingen[2.2] estimate that possibly one half of all fatalities occurring annually in survivable aircraft accidents could be prevented if aircraft design was based on conditions for human tissue protection during impact. These authors present three principles for delethalization within the cockpit of light aircraft:

1. Eliminate and/or redesign cockpit objects which can cause puncture wounds upon bodily impact.

2. Design and install a restraint system (seat belt and shoulder harness) which will securely hold a human body under brief transient forces as high as 25 g. The occupant seat must be designed to stay intact at such forces.

3. Design instrument panels and all other areas of likely body contact so that upon impact the greatest amount of deformation and material rearrangement would occur in the structures and not in the human body.

Figure 2-2 shows the number of injury areas for 800 survivors of light aircraft crashes. This data points out the fact that the head is most intolerable to impact and must be most adequately protected.

Figure 2-4 shows g-force curves obtained from catapulting an instrumented dummy head against a typical unprotected light aircraft instrument panel. As noted, the lowest impact velocity produced a peak g value of over 160 g. The rigid panel did not deform so the head impacted the panel over a very small area. The forehead is the strongest part of the face, but according to one study[2.1] it cannot withstand a force of 80 g on one square inch of area without fracture. Therefore, all impacts depicted in Figure 2-4 would cause fatal head injuries in aircraft crashes.

EXAMPLE OF DESIGN FOR IMPACT SURVIVAL

Aluminum honeycomb is an extremely effective mechanical energy absorber and is finding increasing use in the control of forces exerted on decelerating objects.[11] Materials such as sponge, solid rubber, cork, foams, and paper wadding generally exhibit spring characteristics with the attendnat rebound problem. Aluminum honeycomb, however, has the unique property of failing at a constant load with complete dissipation of energy that would otherwise be released in rebound. The initial peak at which compressive failure begins can be eliminated by pre-stressing the honeycomb core to produce slight initial compressive failure. When exposed to further loading the pre-stressed core proceeds to carry the crushing load at a near linear rate. Such control appears vital in safeguarding human occupants in aircraft crash conditions. As an example of aluminum honeycomb's ability to attenuate human impact loads, consider this representative case:

The impacting mass is the human head with a weight of about twelve (12) pounds. Assuming that the occupied aircraft seat does not fail at the floor attach points and that the occupant is restrained by a seat belt, the head could be expected to impact a forward surface (instrument panel, seat back, etc.) at a velocity of over 40 ft./sec. Under these conditions, approximately 320 foot-lb. of kinetic energy will be dissipated at head impact. Without a yielding material to absorb this energy, death is certain. However, cursory calculations indicate that such an impact upon an aluminum honeycomb (3003 aluminum, 3/4 inch cell and, .004 inch foil gage)[12] section with a thickness somewhat over 3 inches could be tolerated by the human head.

$$\text{Kinetic Energy at Impact} = E_k = \frac{WV^2}{2g} = \frac{(11.5)(42)^2}{64.4} = 320 \text{ ft.-lb.}$$

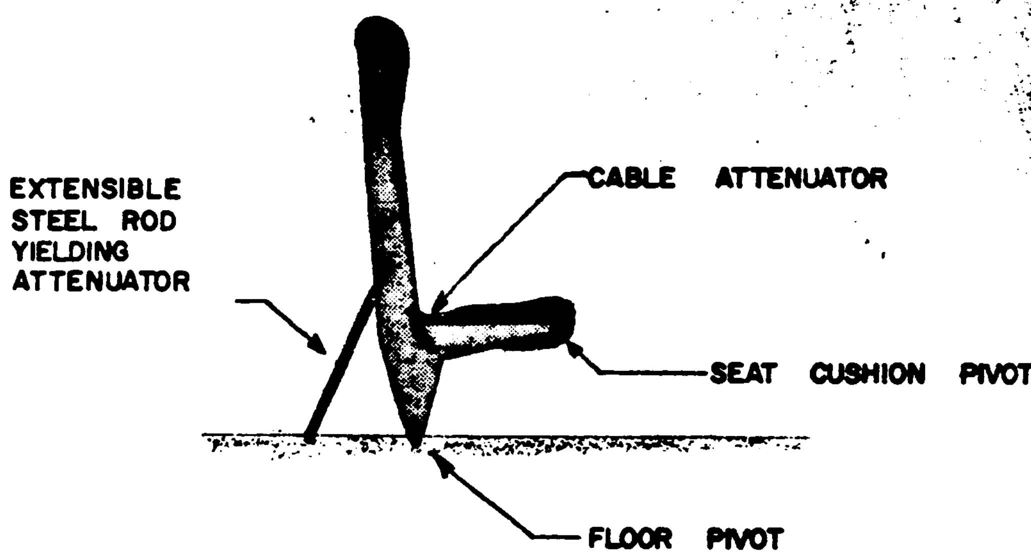
The rate of deceleration is approximated by:

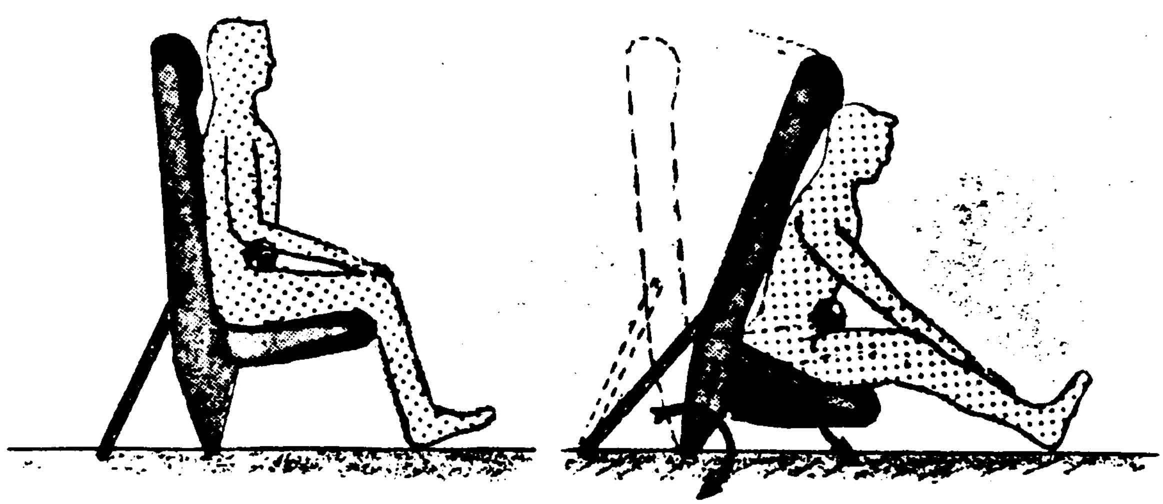
$$A = \frac{V^2}{2S_c}$$

It may therefore be practical to pad areas of likely body contact in all types of aviation vehicles with honeycomb or similar material to improve survival.

20-G ENERGY ABSORBING SEAT

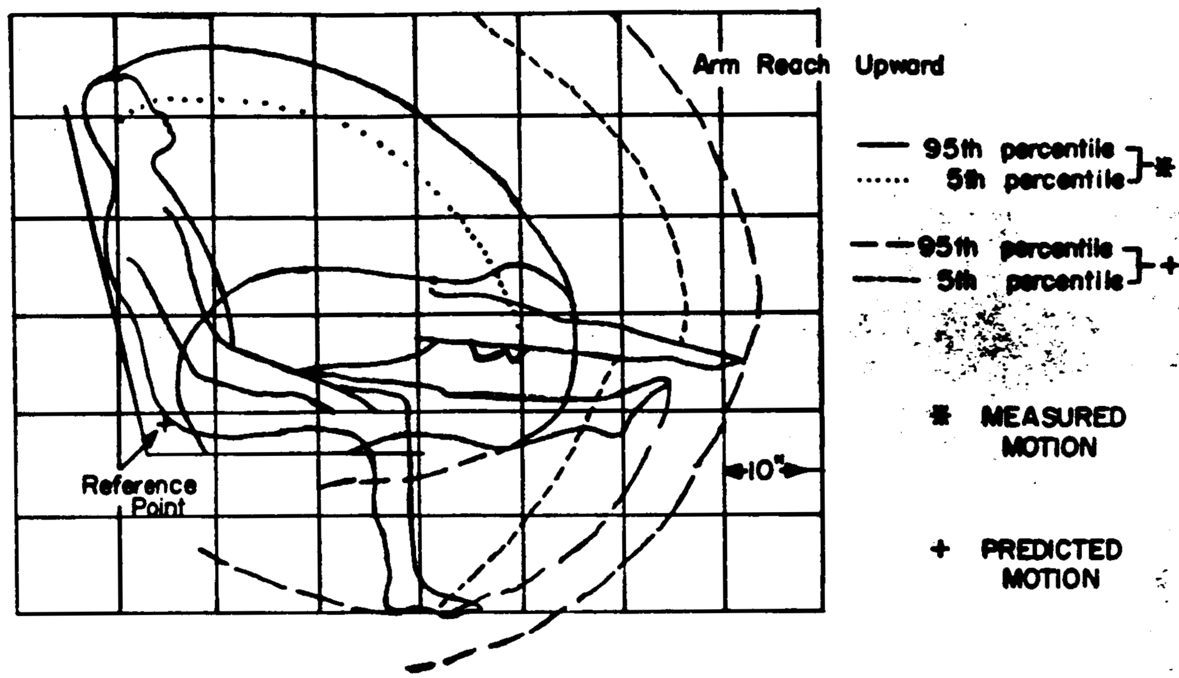
(REF. U.S. NAVY CONTRACT N600 (19) 62456)
NET CUSHION HELICOPTER SEAT
STENCEL AERO ENGINEERING CO.





BEFORE IMPACT AFTER IMPACT

RESTRAINED HUMAN IMPACT ENVELOPE



RESTRAINED HUMAN INJURY AREAS
LIGHT AIRCRAFT CRASHES

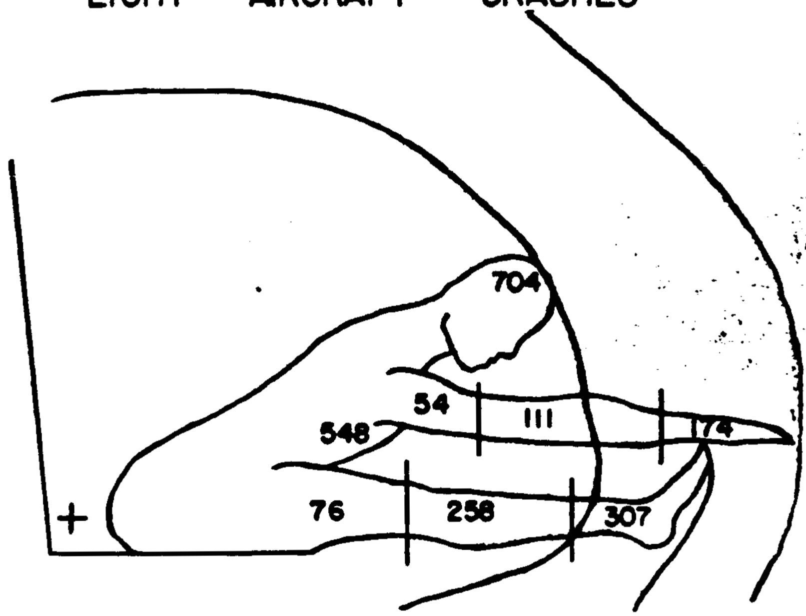
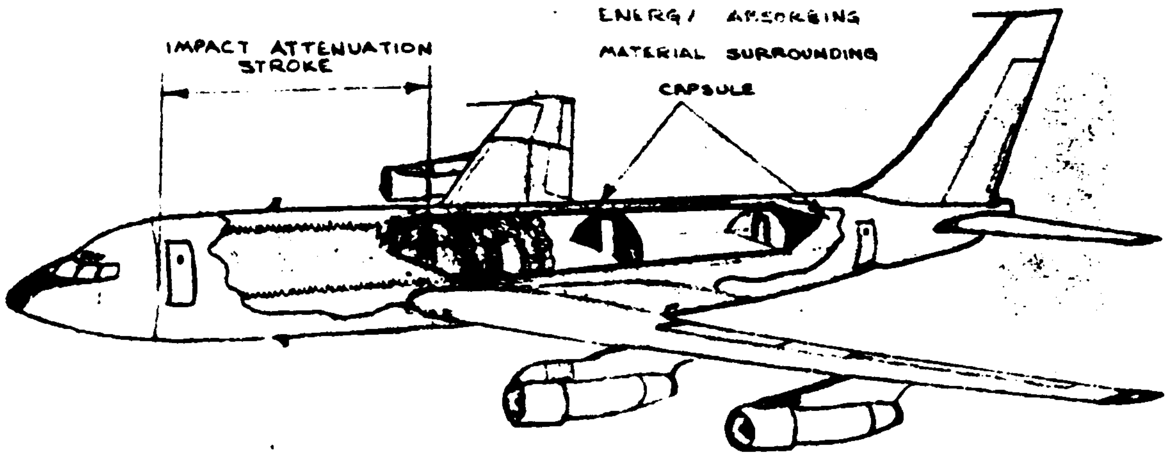


FIGURE 2-3



707 TYPE AIRCRAFT

CRASH CAPSULE CONCEPT

G-FORCE CURVES OBTAINED WITH HEAD IMPACTS ON A TYPICAL LIGHT-AIRCRAFT INSTRUMENT PANEL AT VELOCITIES OF (1) 17.6 FT/SEC, (2) 26.7 FT/SEC, AND (3) 42.2 FT/SEC.

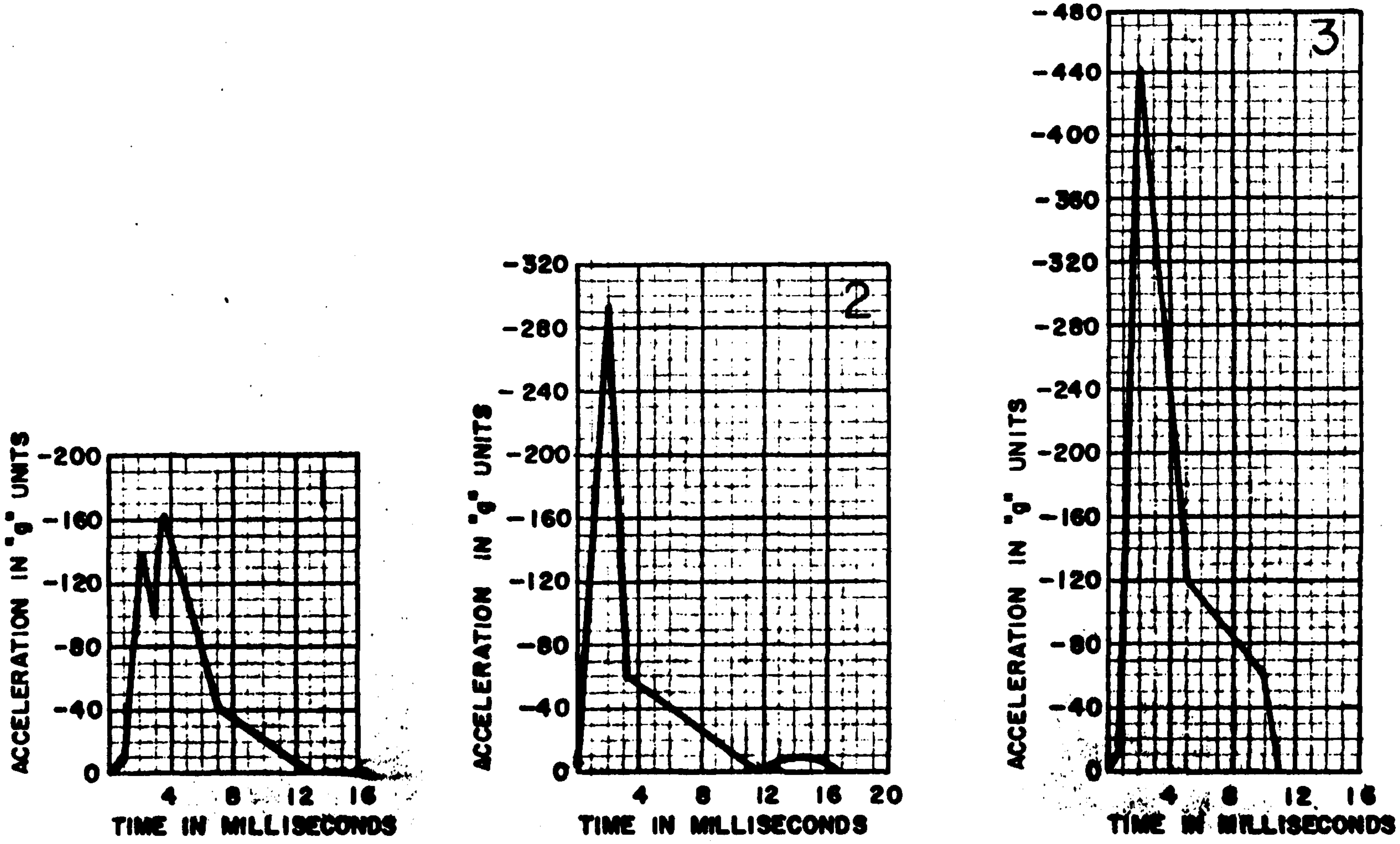


FIGURE 2-4

2-12

FIGURE 2-

3.0 EXTERNAL TO FUSELAGE SURVIVAL IMPROVEMENT METHODS

The typical aircraft fuselage has very limited potential for energy absorption upon impact. The velocity must be reduced to within the limits expressed in Figure 1-1 if internal survival improvements are to be of any value.

In the kinetic energy equation ($E = \frac{1}{2}mV^2$), it is seen that a reduction in velocity and/or mass will reduce the impact energy. Several concepts are deemed practical for reducing aircraft mass and/or velocity before an anticipated crash. However, velocity reduction is by far the most effective and necessary means to reduce impact energy.

There are generally three methods to externally reduce aircraft velocity. They are: The use of a drogue parachute near or on the ground; the use of retro-rockets, and/or the use of a descent-recovery parachute from in-flight.

In-Flight Recovery

For in-flight recovery, aircraft recovery parachutes would be deployed at the time of an uncontrollable aircraft descent. If it were possible, rapid ejection of the fuel would aid in order to decrease weight as well as to lessen the fire hazard upon ultimate impact. Aircraft mass could also be decreased by wing and empennage severence. The practicality of such severences requires further study.

Retro-rocket deceleration near the ground or a combination of a parachute/retro-rocket system represent other feasible in-flight survival concepts. Again, weight decrease before impact would be an important criteria.

If it were not practical to save the complete occupied sections of disabled aircraft then individual recovery means would be in order. There would be the need to eject single occupants or groups of occupants free and clear of the aircraft. Protective clothing or complete encapsulation would be required so that every individual could survive the environment outside of the aircraft. Parachutes or other types of decelerators would deliver the survivors safely to the ground. Individual ejection becomes increasingly difficult and less practical as the number of passengers in a given aircraft increase.

Take-Off and Landing Emergencies

Some crashes result from failure of the aircraft prior to lift-off or during its landing roll. A drogue parachute for deceleration would be effective in such conditions. The deployment of a drogue parachute could be used which imposes a force of about 1g upon the plane's structure without the need for structural strength increases on current aircraft. The decelerative force of the drogue, plus reverse power and braking, would make any impact less severe and probably the aircraft could even be stopped within runway limits. Current aircraft brakes, and reverse thrusting can only provide a fraction of the decelerative force that can be provided by a drogue parachute.

Airport emergency crash barriers provide another positive means for the reduction of fatal accidents in the take-off and landing phase of operation.[6] Various research has shown that both tail hook and net arresting means are feasible and possible for private, commercial and military transport aircraft. The application of this technique would probably be more practical at major airports having heavy traffic.

The landing phase of operation accounted for 50% of all U.S. Air Carrier accidents in the 1960-1964 period. A similar statistic exists for U.S. general aviation in 1963. The severity of adverse landing conditions could be lessened by the drogue concept or crash barrier concept mentioned for take-off and landing accident survival. Redesign for both aircraft and runway may be required for crash barriers to be functional while only aircraft re-work would be anticipated for the installation of a deceleration parachute. The drogue chute technique would probably prove to be the more useful and flexible method since deployment of a drogue could be made at any place and is not restricted to airport areas.

From 1960 to 1964, take-off crashes accounted for nearly 14% of all accidents and about 25% of all fatalities in U.S. commercial aviation. Landing accidents represent one-half of all accidents and 15% of the total deaths.

In general aviation for any given year, approximately 60% of all accidents occur during the take-off and landing phases of operation. These statistical data show that the landing and take-off operational phases, although having fewer fatalities, are by far the most frequent form of accident. A runway level accident may result from many and various causes; however, the causes and results discussed here will be confined to the case of an aircraft overrunning the hard-surfaced runway. Table I lists possible causes and results of an aircraft overshoot.

TABLE I

CAUSES FOR OVERSHOOT	POSSIBLE RESULTS
1. Overshoot of touchdown point	1. Loss of directional control, leading to impact with natural (water, uneven terrain, trees, etc.) or man-made structures.
2. Excessive touchdown speed	2. Human injury and/or aircraft damage and fire.
3. Failure of reverse thrust and/or brakes	3. Entrapment of passengers and crew due to structure distortion upon impact.
4. Wet runway (hydro-planing) conditions with all available reverse power and braking	
5. Aborted take-off because of a system malfunction	

For overrunning conditions, shown to be statistically significant in Figure 3-7, it is evident that some additional means for decelerating an aircraft during its runway roll is necessary. An emergency drogue parachute system provides an already proven solution.

DROGUE PARACHUTE CONCEPT

Narrative

The use of a parachute as an auxiliary aircraft brake during approach, touch-down, and ground roll is a tried and proven concept. The history of this decelerative means dates back to 1923, (ASD-TR-61-579).

The development of the high-speed jet aircraft brought about the most important use for deceleration parachutes. The high wing loadings of a jet powered aircraft necessitate high landing velocities which result in long roll-out distances. The deployment of a parachute near or at the time of touch-down has proven to be a very efficient means for military jet aircraft deceleration whether it be an emergency or standard procedure. Commercial and private aircraft are currently structured such that they could be fitted with drogue parachute systems for deceleration assistance in landing and aborted take-off emergencies.

Many overshoot accidents could be prevented in U.S. commercial aviation by the use of a drogue parachute. One example is provided by the overshoot of a Continental Air Lines, Inc., Boeing 707 at the Kansas City, Mo., airport on 1 July 1965. The CAB accident report[9] states that the aircraft made a firm landing in heavy rain 1050 feet past the approach end of the 7000 foot long runway 18. The flight recorder showed a touch-down velocity of 137 KIAS (232 ft./sec.). The landing weight was under the FAA 175,000 pound maximum gross weight landing restriction. The investigation revealed no evidence of pre-impact failure or discrepancy in the tires, brakes, or anti-skid system. The FAA Board concluded that the plane was in safe condition and the crew qualified to perform the landing at the Kansas City Airport. Yet, because of hydroplaning of the landing gear wheels, the applied braking force plus maximum reverse thrust was ineffectual and the aircraft overshot the runway at an estimated 39 KIAS. Calculations show that the aircraft needed approximately 7000 feet of roll-out distance to come to a complete stop. A total of 5 people received minor injuries. Aircraft damage was substantial, but no major fire occurred after the plane impacted and passed through the ILS localizer antenna building, struck a dirt blast mound, slid up over the mound, and finally stopped with the nose section in the perimeter road between the blast mound and a river levee. This accident could have been simply prevented if an emergency drogue means of deceleration had been available.

DROGUE PARACHUTE COMPUTER ANALYSIS

A computer program has been written and is used in this study to approximate the ground roll deceleration of an aircraft. Aircraft resistance is represented in terms of wheel braking, reverse power, rolling friction, and aerodynamic drag. The program prints out data on time, parachute drag, aircraft acceleration, velocity, distance, and yaw angle. Aircraft stopping conditions are compared both with and without drogue parachute assistance.

ANALYTICAL RESULTS

Figures 3-1 & 3-2 present data reduced from the drogue parachute program. The first of these figures shows the initial drogue parachute g-force necessary to stop an aircraft in a given distance for various resistance conditions (represented by resistance coefficient "K"). The results shown are representative for the landing conditions of a DC-8 or Boeing 707 type aircraft. For the curve labeled K=0.08 (wet runway hydroplaning with reverse thrust) and with zero initial drogue force, the transport would come to a stop at about 7000 feet of roll-out distance - the same distance that would have been required in the Continental accident previously discussed. However, the aircraft could have been stopped in its normal distance (about 2800 ft.)[8] from touch-down if an initial drogue parachute force of only 0.5 g had been available. Figure 3-1 further shows that such a transport could be safely stopped at a distance of less than 3000 feet for a worst case condition of K=0.01 (no brakes / reverse thrust failure) with an initial drogue force of 1.0 g.

Figure 3-2 shows an estimate of velocity versus time for a Boeing 707 type aircraft's roll-out after landing. Curve(1) clearly shows the beneficial effect of a drogue parachute. The velocity decay is most rapid in the first few seconds after landing since the drag force of the parachute is directly proportional to the square of the velocity. As the aircraft velocity decays, curve (1) assumes a more gradual slope and the parachute force decreases more slowly. A comparison of curves (1) using a 1 g drogue with no reverse thrust or brakes and curve (2) (normal landing-no drogue) reveals that there would be very little, if any, difference between the stopping times or distances of the two conditions.

Figures 3-1 & 3-2 and curves (3) and (4) show that without braking or reverse thrust, conditions are unsafe for transport aircraft landing. The velocity decreases too slowly with time, and the craft would probably exceed the available runway length.

Figures 3-1 & 3-2 represent only landing conditions for one aircraft type. However, from this example, it is apparent that a drogue deceleration parachute would also offer much assistance in aborted landing and/or take-off conditions for other weight aircraft.

In-Flight Emergencies

Aircraft accidents that are a result of mid-air explosion or collision are usually without warning. Because of this lack of warning time, the crew and passengers can do very little toward protecting themselves to survive the accident. On the other hand, when an aircraft accident is a result of a fire, air turbulence, engine failure, structural and/or control failure, or other equipment malfunction there is usually sufficient time and altitude and a good chance that the crew and passengers could perform some corrective action. In these aircraft accidents the occupants could be protected and could prepare themselves for impact if better and new survival techniques were employed. At least half of the 18 major air carrier fatal accidents in the period from 1962 through 1964 (includes over 90% of the fatalities) had sufficient time and altitude to apply an emergency recovery system for survival. The internal protective techniques presented in Section 2.0 coupled with external recovery methods for reducing crash impact velocity would certainly improve the chances of survival. Several avenues are open for survival improvement by using external recovery systems.

Accident statistics for commercial aviation, Figure 5-7, general aviation, Figure 6-4, and military transport aviation show that the majority of aircraft fatalities result from accidents which occur during the enroute phase of operation. Thus, improved means of protecting occupants in these flight phases are significant. During the five-year period (1960-1964) reported by Figure 5-7, over half of the fatalities (59%) for U.S. Air Carriers were precipitated by in-flight failures. In 1963 alone, over 200 deaths were caused by the enroute failures of general aviation aircraft (reference Figure 6-4.)

There were 1642 fatalities during the period from 1960 through 1964 as a result of 64 fatal accidents. These fatalities were distributed in categories as shown in Figure 5-7, and may be further summarized as follows:

	Percent of all accidents	Percent of all fatal accidents	Percent of all fatalities
Take-off and Initial Climb	14	20	25
Enroute	26	45	60
Approach and Landing	50	30	15

It is evident that enroute accidents account for the greatest number of fatal accidents, and that each of these in turn result in a greater number of persons killed.

REPRESENTATIVE LIST OF MAJOR FATAL AIR CARRIER ACCIDENTS FROM 1962 to 1964*

Date	Type Aircraft	Number Killed	Type of Accident	Sufficient Warning
3-1-62	707	95	initial climb, 1600 ft. alt., control system malfunction	yes
3-15-62	L-1049	107	in flight, mid-air explosion, enroute	no
5-22-62	707	45	in flight, dynamite explosion at 39,000 ft.	no
9-23-62	L-1049	28	in flight, engine fire, ditched into sea	yes
11-23-62	Viscount	17	in flight, hit birds at 6000 ft., loss of control	yes
1-29-62	V-812	8	approach & go around, icing, loss of pitch control	?
2-12-63	720	43	in flight, 17,500 ft. break-up, cause unknown	?
6-3-63	DC-7C	101	in flight, 14,000 ft., debris in ocean, cause unknown	?
12-8-63	707	81	in flight, 5000 ft., sudden fire, crashed in flames	yes
2-22-64	DC-8	58	in flight, loss of stability control in turbulence	yes

Date	Type Aircraft	Number Killed	Type of Accident	Sufficient Warning
3-12-64	DC-3	5	approach, descent below obstructing terrain	no
5-7-64	F-27	44	in flight, pilot shot by passenger, loss of control	yes
7-9-64	V-745	39	initial approach, fire aboard, loss of control	yes
11-15-64	F-27	29	premature descent hit terrain	no
12-24-64	L-1049	3	approach, hit terrain, bad visibility	no

*This is a partial list of accidents representing 90% of the accident fatalities from 1962 through 1964.

A review of the accident list presented shows that half of the fatal in-flight accidents occurred with sufficient altitude and time to employ an aircraft emergency external recovery system as well as internal survival devices. External recovery methods would be essential for survival in these cases. From 50% to 70% of the fatalities in these accidents (362 to 514 of the 732 fatalities listed) might have been prevented with the aid of external recovery system methods.

Occupant Recovery From Uncontrollable Aircraft

Although the recovery of a small aircraft solely by parachute appears practical, the recovery of an entire large transport aircraft solely by parachute does not appear practical because of inherently greater proportions of fuel and structure weight, and because of the lengthy size of the parachute system required. Simple parachute systems for heavy payloads become too lengthy in size and take too much time for deployment to permit aircraft recovery from low altitudes.

Aircraft speed, altitude, attitude and sink rate are the primary parameters to be considered when designing a mid-air recovery system. It is likely that one or more of these variables will be such that the pilot's attempts to control the descending craft would be unsuccessful. A stabilizing system would therefore be necessary to accomplish two necessities: (1) maintain the craft in an attitude conducive to occupant escape; (2) slow the descent velocity of the disabled craft so that safe escape and recovery of all occupants may be better controlled.

Figure 1-3 lists the first three proposed in-flight survival methods as descent parachute, retro-rockets and retro-rockets plus stabilization chute. It is noted that any appendage severence would be optional. However, some sectional severence would probably be desired so that the recovery system could have a minimum weight and function speedily.

A common exit ejector is listed as a survival mode for individual recovery from disabled aircraft. With this method all occupants would have to leave their seats and move to a pre-assigned exit. In passing the exit area, they would have to be rapidly fitted with protective garments or perhaps completely encapsulated. If the system were designed for individual escape, each occupant would receive a parachute or other decelerator, exit the aircraft, descend to the terrain under a decelerative force, and impact and survive according to individual ability.

A common exit ejector survival concept is categorized as infeasible with more than a few persons because of the time and difficulty for each occupant to move from his seat to the assigned exit, to say nothing of the environmental problems faced alone once away from the aircraft. Often times the violent aircraft motions would prevent controlled passenger movement.

Intact fuselage methods hold more promise for occupant mid-air recovery. Each person would remain seated, securely restrained by safety belts, both seat and shoulder. With passengers in their seats, there would be less injury and panic than if they were required to move toward an exit before escape. One proposed group occupant recovery system, shown in Figure 3-3, would function in much the same way as present cargo airdrop systems. The escape operation would be to sever or mechanically disconnect the empennage section and pull it free and clear of the main structure. The aft moving tail section pulls an extraction chute out whereupon the extractor inflates and produces the necessary extraction force on the capsule. The capsule is then unlocked and extracted from the fuselage. Once clear, the load transfer disconnect operates and recovery parachutes are deployed and inflated to provide equilibrium descent of the passenger section. Such a system is feasible at minimum altitudes of 500 to 1000 feet.

Figure 3-4 shows a method in which a small aircraft is recovered intact.

<u>Attenuators</u>

There are three general methods by which ground-impact shock forces can be reduced: (1) shock attenuation by ground penetration spikes; (2) shock attenuation without penetration by crushable structures; (3) pre-contact retardation by rockets. Although the three methods employ distinctly different devices, they all satisfy the main objective of a shock-attenuation system; to reduce velocity at impact in a more gradual and controlled manner. Depending on the fragility of the load, these devices must control the rise time and the magnitude of the imposed force during deceleration. An added requirement for the landing-deceleration system is the prevention of toppling of the load during or after the deceleration phase. Figure 3-5 illustrates the recovery of an intact transport fuselage by means of a parachute/retro-rocket combination.

The overall weight of any recovery system is mainly dependent upon the payload weight to be recovered and the impact velocity that can be tolerated. The dependence of recovery system weight on velocity is shown in Figure 3-6. Assuming the payload to have some inherent structural attenuation, it is estimated that a 40 ft./sec. impact velocity would be tolerable to seated occupants. It is further shown that a 40 ft./sec. impact velocity can be provided at only 2½% to 3% of the payload weight, but that the recovery system weight required goes up sharply if lower impact velocities are desired.

Small aircraft such as those used by general aviation can be recovered intact. However, large transport aircraft being very heavy would require large unwieldy parachutes for recovery. For this reason, transport aircraft may require retro-rocket/parachute combinations to accomplish reasonable compactness. In addition, the actual weight recovered may be reduced considerably by severance of appendages and recovery of the fuselage only; or by extraction of a cabin interior to the fuselage. Weight savings possible in this manner are shown in Figure 3-7. Thus, a transport recovery system may weigh anywhere from 9% to 2% of the empty aircraft weight dependent on the recovery concept.

FIGURE 3-1

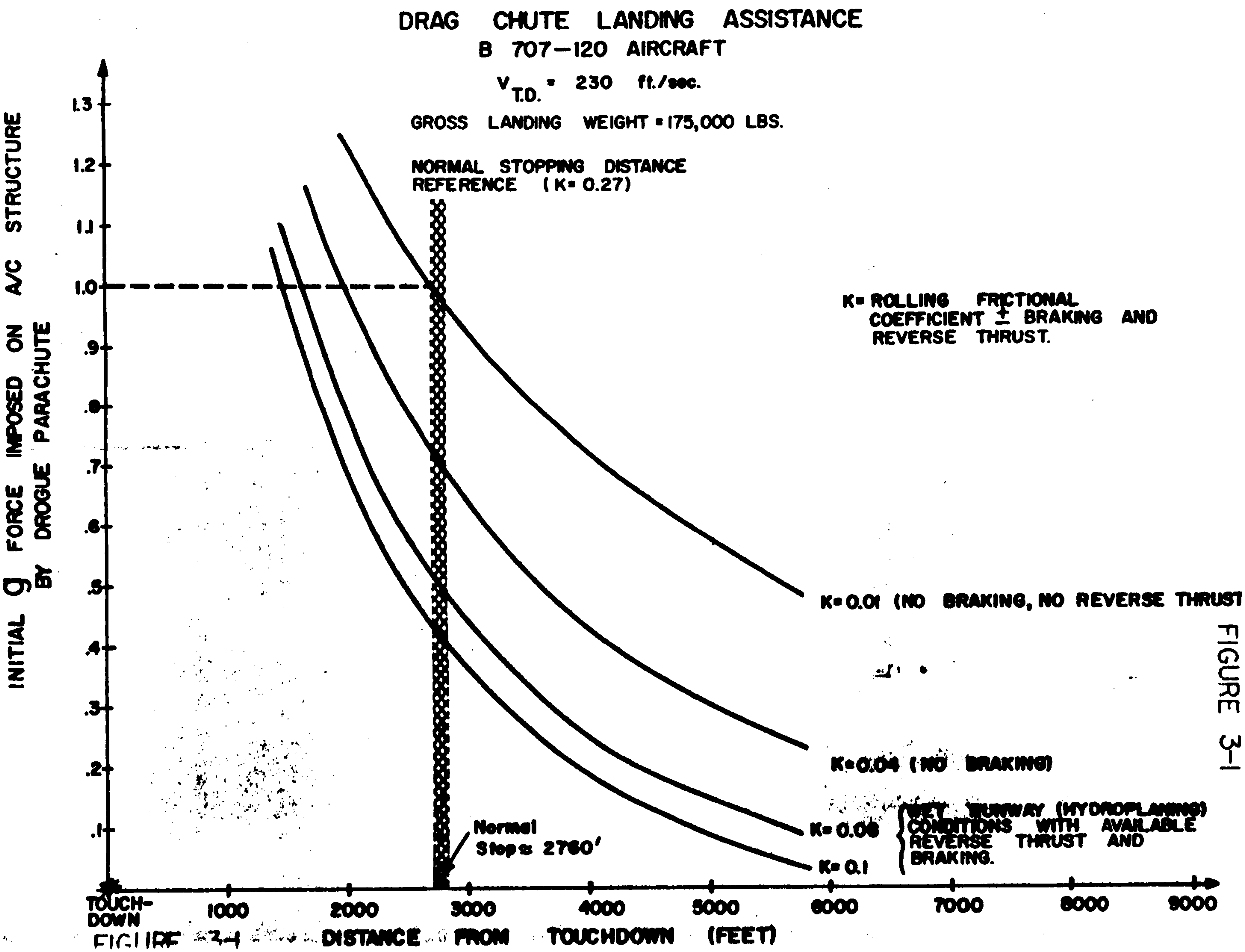


FIGURE 3-1

3/3

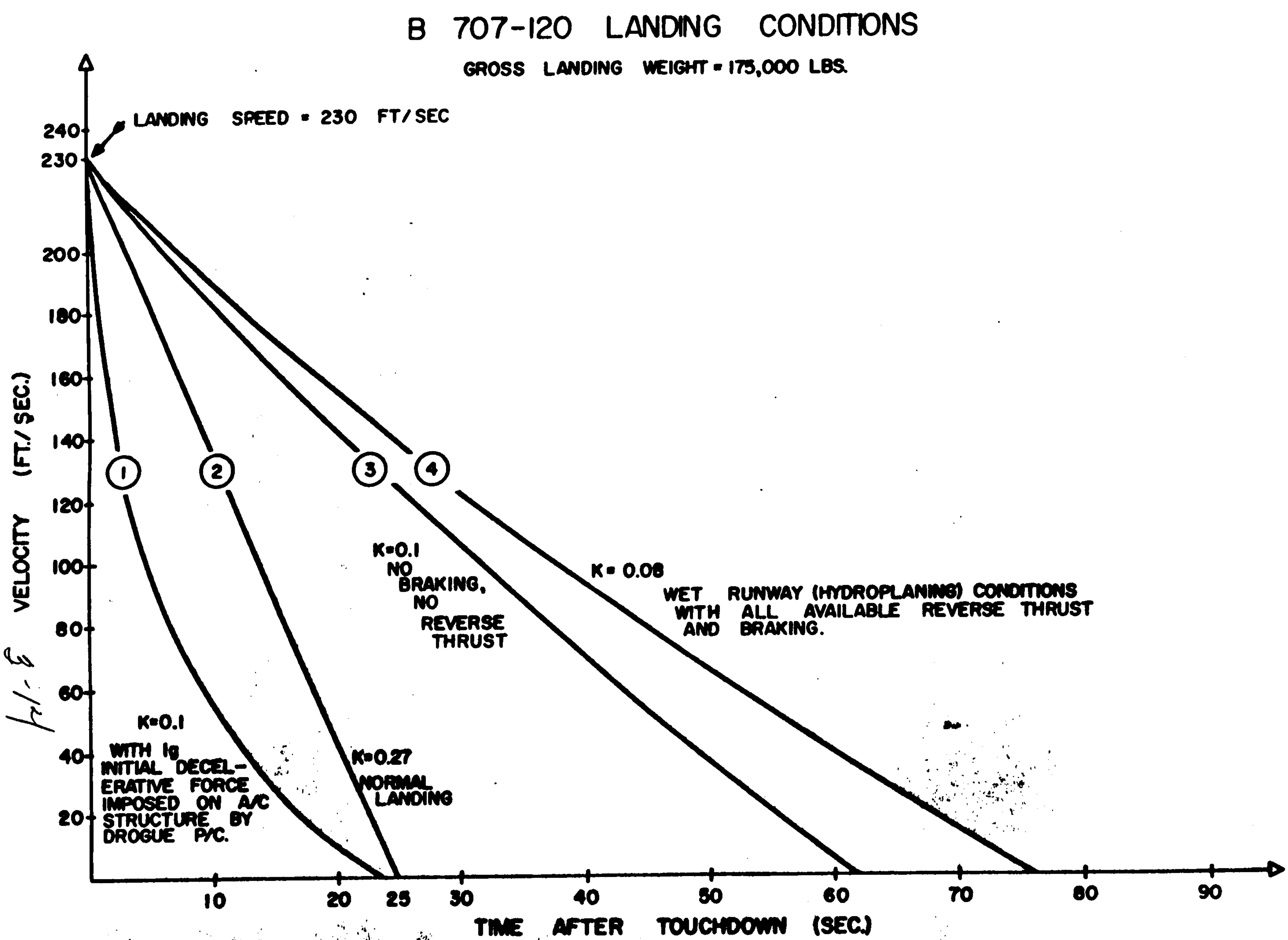


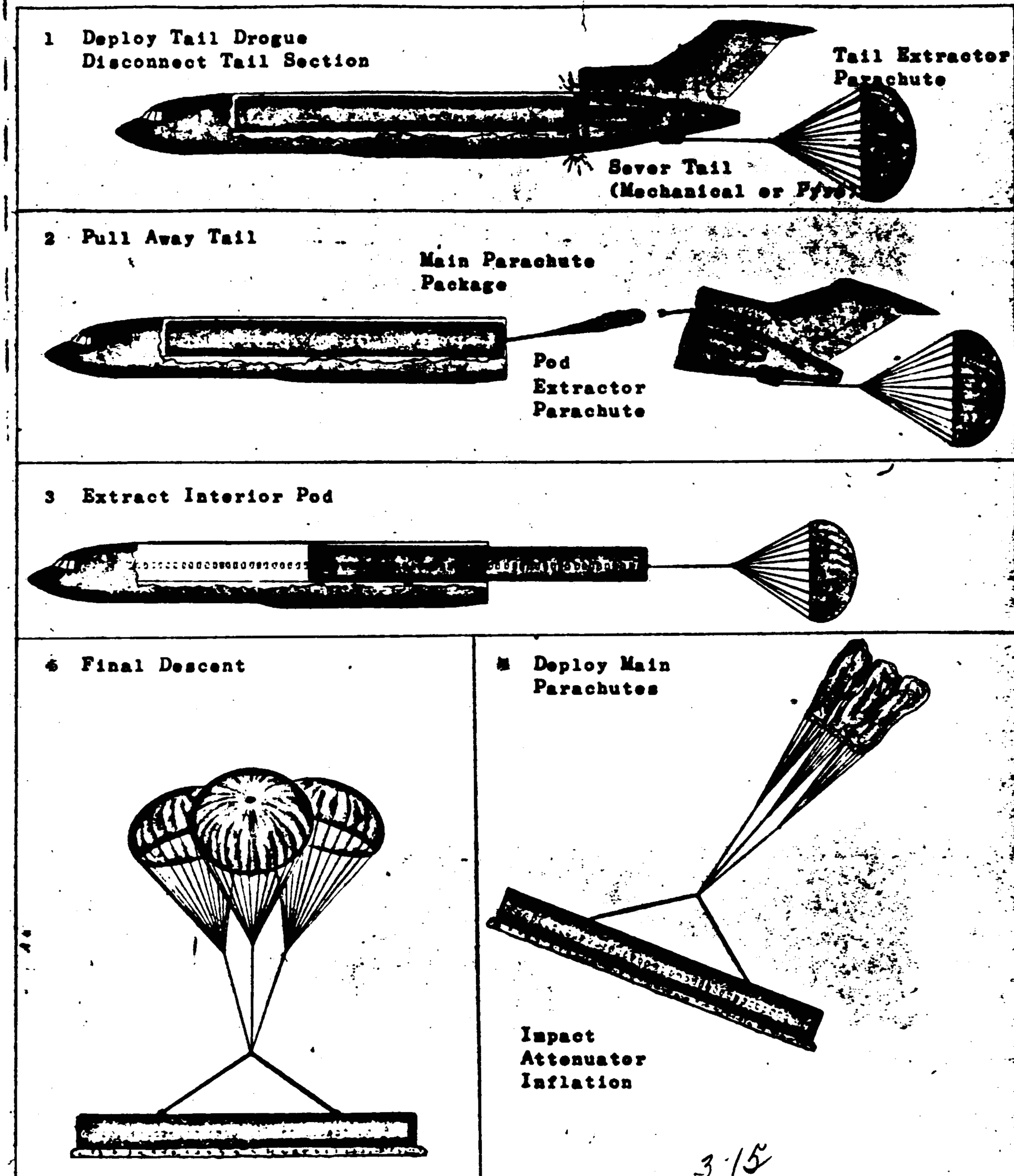
FIGURE 3-2

3-14

FIGURE 3-3

INTERIOR POD RECOVERY

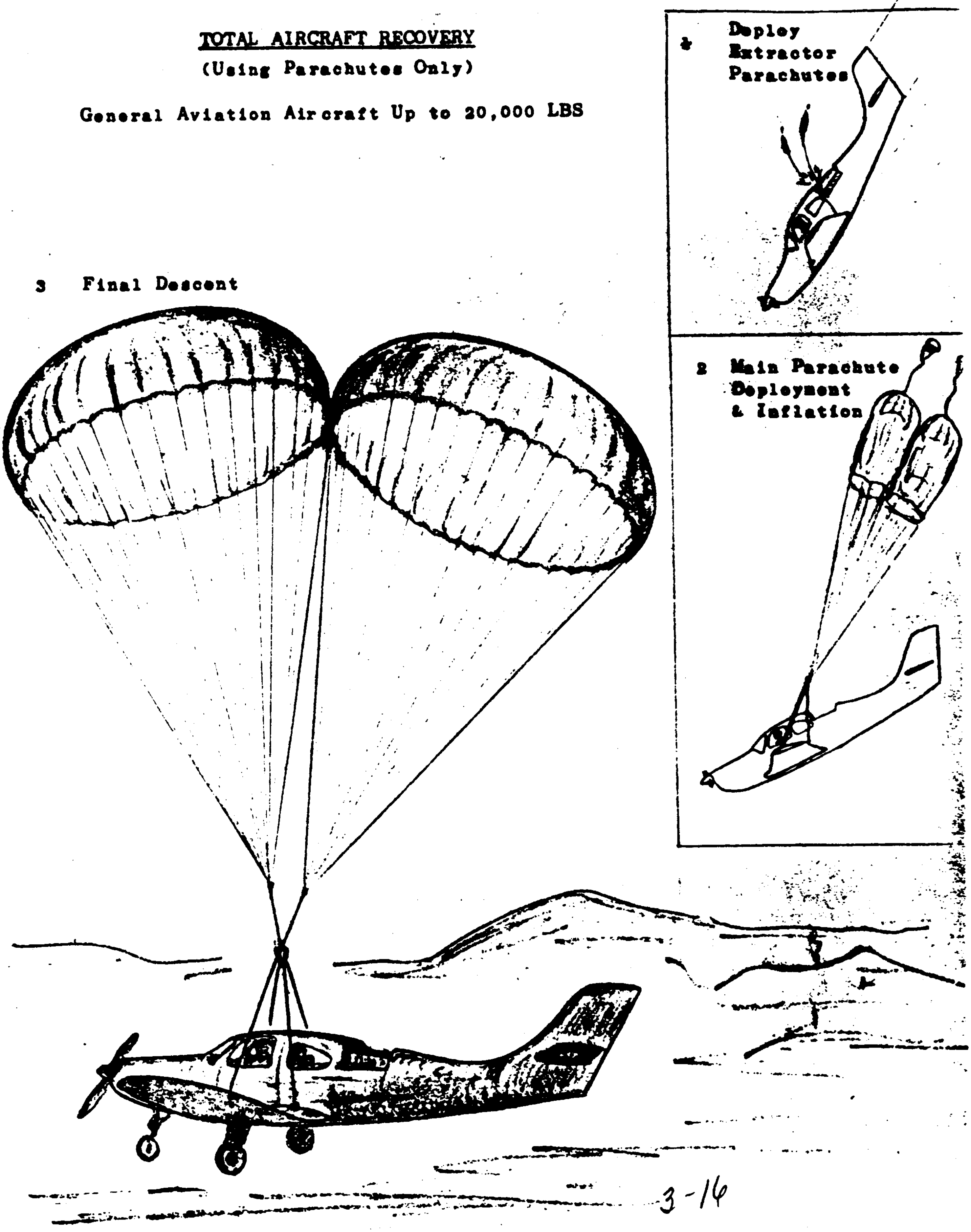
Extraction Sequence
Executive Type Aircraft



TOTAL AIRCRAFT RECOVERY

(Using Parachutes Only)

General Aviation Aircraft Up to 20,000 LBS



TRANSPORT FUSELAGE RECOVERY

Fuselage Weights up to 200,000 LBS

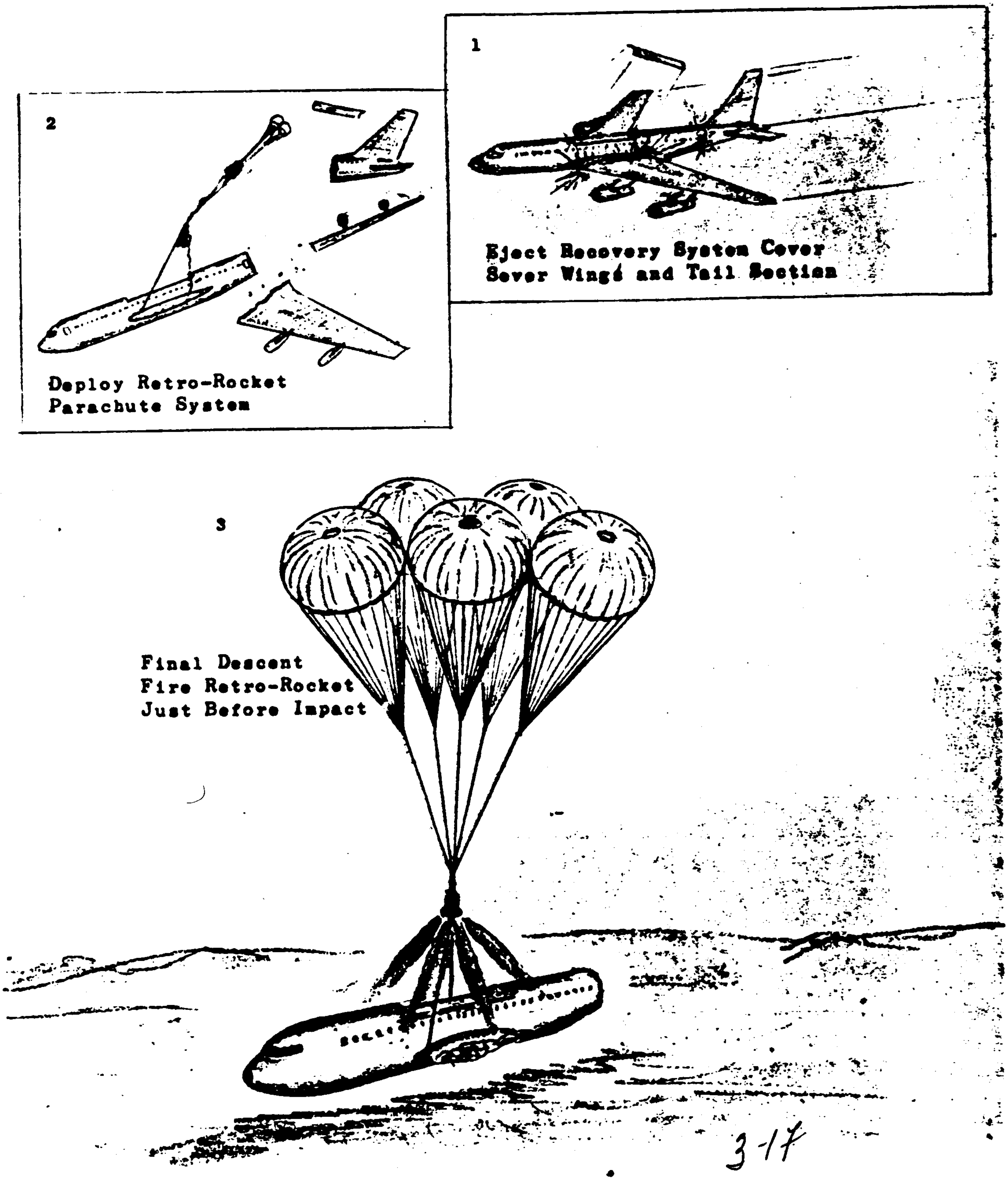
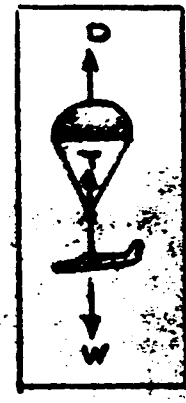


FIGURE 3-6

RECOVERY SYSTEM WEIGHT

(Retro-Rocket + Parachute Concepts)



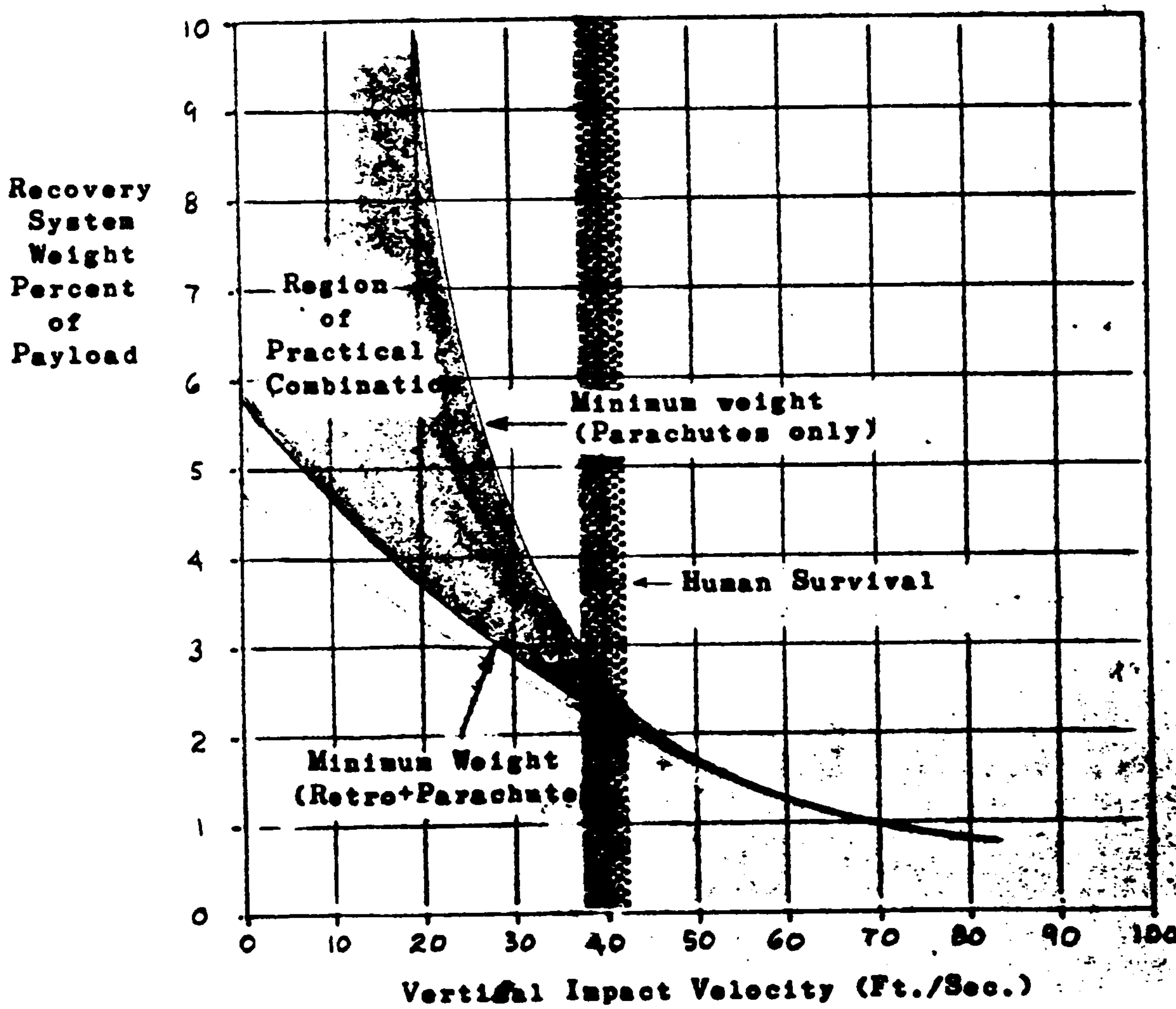
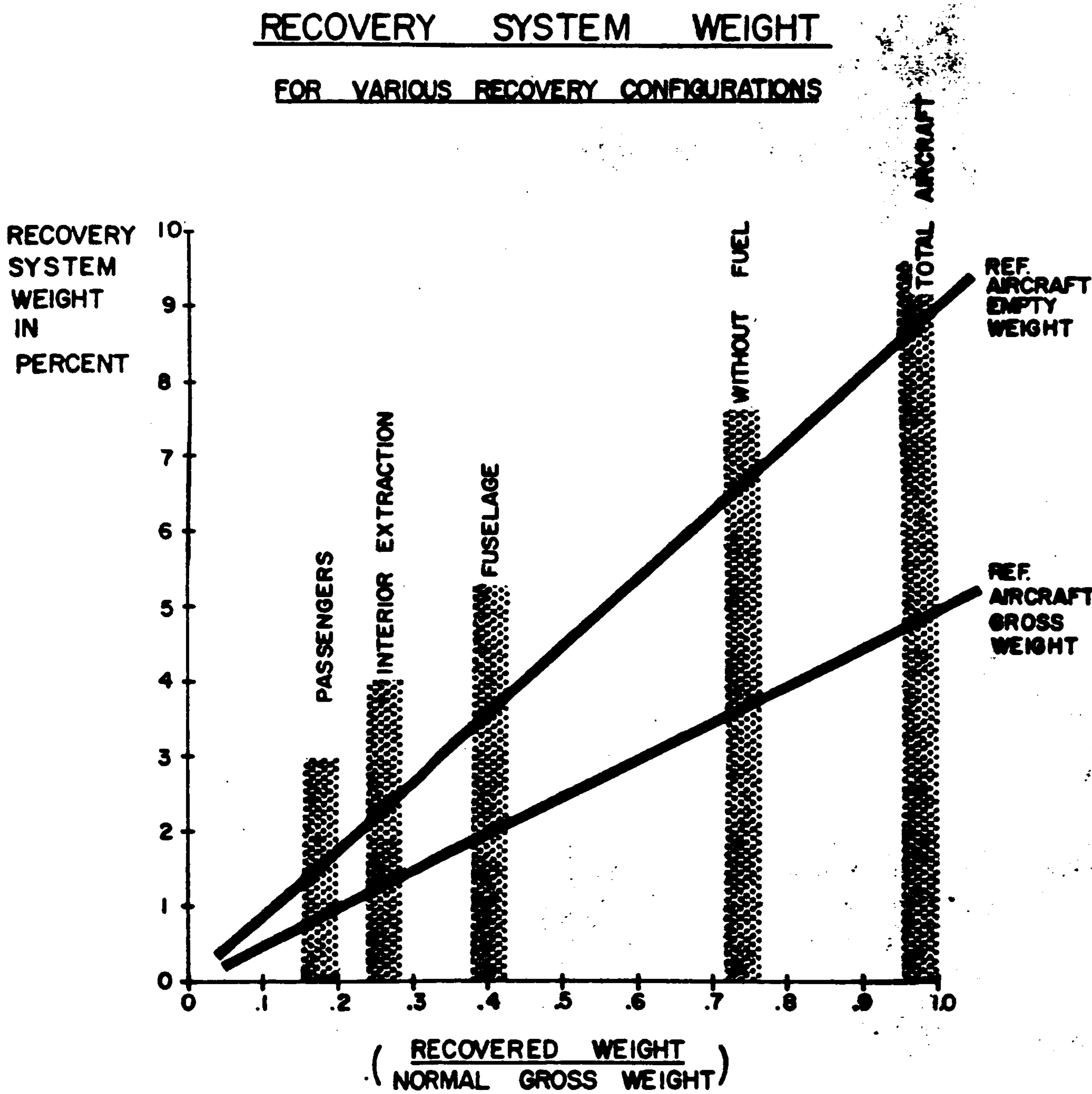


FIGURE 3-7


RECOVERY SYSTEM WEIGHT
FOR VARIOUS RECOVERY CONFIGURATIONS
RECOVERY SYSTEM WEIGHT IN PERCENT
0
1
2
3
4
5
6
7
8
9
10
PASSENGERS
INTERIOR EXTRACTION
FUSELAGE
WITHOUT FUEL
TOTAL AIRCRAFT
REF. AIRCRAFT EMPTY WEIGHT
REF. AIRCRAFT GROSS WEIGHT
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
(RECOVERED WEIGHT / NORMAL GROSS WEIGHT)

4.0 STRUCTURAL FACTORS

The Federal Air Regulations (F.A.R.) provide an extensive guide to aircraft structural requirements that must be met by the manufacturers. These regulations apply to all civilian aircraft and are presented in parts as they would apply to specific types of aircraft. The parts of concern to this study are: F.A.R. Part 23, Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes; and F.A.R. Part 25; Airworthiness Standards; Transport Category Airplanes. Many other Airworthiness Standards exist, although they have not been immediately applied to this study.

Manufacturers currently use the F. A. R. requirements for occupant seating restraint as intended to meet emergency landing conditions. As outlined in Part 25, Section 25.561; the design requirements for loads are (statically applied):

Upward 2.0 g (assuming a 170 lb. occupant)
Forward 9.0 g
Sideward 1.5 g
Downward 4.5. g

The same values apply to surrounding objects in the cabin that could come loose and strike the occupant. In an aircraft crash the dynamic loads exceed these values and may reach 40 to 50 g's for short durations, measured in milliseconds. If the seats are unable to absorb this high load impulse they will break loose. The need for ductile, energy absorbing seat attachment has been pointed out repeatedly by test evidence and is being studied by Av SER (3). Manufacturers are aware of the discrepancy between static loads and dynamic loads and have been giving attention to the problem. The 2.0 g upward and 1.5 g sideward loads are likewise suspect for design values since the upward loads may be exceeded by moments developed from the seat 9 g forward loads.

Current jet transports are designed to take roughly 4 g aerodynamic static loads, as applied through the center of gravity. Structural failure of the wing or fuselage sections would be expected to occur at 6 g load values. In crash landings where fuselage failure occurs it is most frequently just forward of the wing and just aft of the wing since the highest bending stresses occur in these areas. The long fore and aft extensions of a fuselage beyond the wing section provide the means for high bending moments on the fuselage.

The landing gear is designed to absorb the energy given by a 10 ft./sec. sink rate without damage at the maximum landing weight for the aircraft. The failure level for the gear is about 12 ft./sec. as the energy to be absorbed goes up as the velocity squared. However, a lightly loaded aircraft may reach sink rates of nearly 20 ft./sec. before failure occurs.

Typical aircraft weight distributions(empty but fully equipped for airline operation) are as follows:

	DC-9	DC-8-61
Wing	23%	26%
Fuselage	18%	20%
Empennage	6%	3%
L. Gear	7%	6%
Power Plants	18%	20%
Systems (elec. Hydr. etc.)	12%	11%
Furnishings	16%	14%

5.0 CERTIFICATED AIR CARRIER ACCIDENT STATISTICS

The Civil Aeronautics Board classifies an aircraft accident as an occurrence incident to flight in which, as a result of the operation of an aircraft, any person (occupant or non-occupant) receives fatal or serious injury or any aircraft receives substantial damage. An aircraft accident incident to flight is further defined as an accident which occurs between the time an engine or engines are started for the purpose of commencing flight until the aircraft comes to rest with all engines stopped, for complete or partial deplaning or unloading. It excludes death or injuries to persons on board which result from illness, altercations, and other incidents not directly attributable to flight operations.

An air carrier is an operator who has been issued a Certificate of Public Convenience and Necessity by the CAB. The two main categories of air carriers are the Certificated Route Carriers and the Supplemental Carriers.

The statistics found in this section were taken for the most part from the "FAA Statistical Handbook of Aviation" and from the Civil Aeronautics Board Annual "Statistical Review." These statistics have been interpreted by the authors for presentation in this report.

Figure 5-1 is a bar graph that shows, each major type and number of aircraft in operation by the certificated route air carriers as of Dec., 1965. Boeing, Douglas, Lockheed and Convair provide the greatest majority of the currently used commercial aircraft. Of the 2104 fixed wing aircraft listed as held by the air carriers, only about 1875 are actually used for passenger operations. The number of commercial aircraft in active service (Figure 5-3) has only varied about 2 1/2 % since 1957. The service provided by these aircraft is shown in Figure 5-2 as accumulated by all the aircraft, and again in Figure 5-3 as an annual average alloted to each aircraft. Currently, the average air carrier aircraft travels 700,000 miles, flies 2100 hours and makes 2200 departures per year. This is accomplished mainly by 1875 of the aircraft represented in Figure 5-1.

The number of commercial carrier accidents is small when compared to the number of aircraft operations. Figure 5-4 shows about 8[illegible] accidents to occur annually. Of these, between 50 and

60 accidents contain minor injuries and inflict substantial damage to the aircraft. Between 10 and 20 accidents contain serious or fatal injuries and cause the aircraft to be totally destroyed. The actual number of persons killed per fatal accident is shown in Figure 5-5. The average number of persons killed in a fatal accident is about 25; however, it is not uncommon for this number to rise above 80 persons in any one crash. The number of fatal accidents in which only 4 or 5 persons are killed is numerous.

These statistics are also presented in terms of operations per accident in Figure 5-6. Accidents averaged and expressed in this manner show an accumulation of about 15 million miles between accidents, and 50,000 hours as well as departures between accidents.

The ratio of the number of operational aircraft (1875) to the number of accidents in a year provides an easily grasped number. That is, how many aircraft exist for each accident. Currently, Figure 5-3 shows that one (1) out of every 23 commercial air carrier aircraft can be expected to incur an accident of some type; related Figure 5-4 indicates that one (1) out of every 37 will incur substantial damage, and one (1) out of every 188 will be destroyed and contain fatalities.

Figure 5-7 shows a breakdown of air carrier accidents by phase of operation for the period from 1960 thru 1964. This period shows the occurance of 402 accidents, 64 of which were fatal and caused 1642 fatalities. Out of the number of accidents, about 14% occur during take-off and initial climb; 26% occur during climb to cruise and enroute; and 51% occur during approach and landing. However, the fatal accidents show a different distribution expressed another way. During take-off one accident in 33 is fatal, enroute one accident in 14 is fatal, and during landing one accident in 20 is fatal. The enroute accident is the most difficult to survive.

FIGURE 5-1

AIRCRAFT IN OPERATION BY
CERTIFICATED ROUTE AIR CARRIERS
DEC. 1965

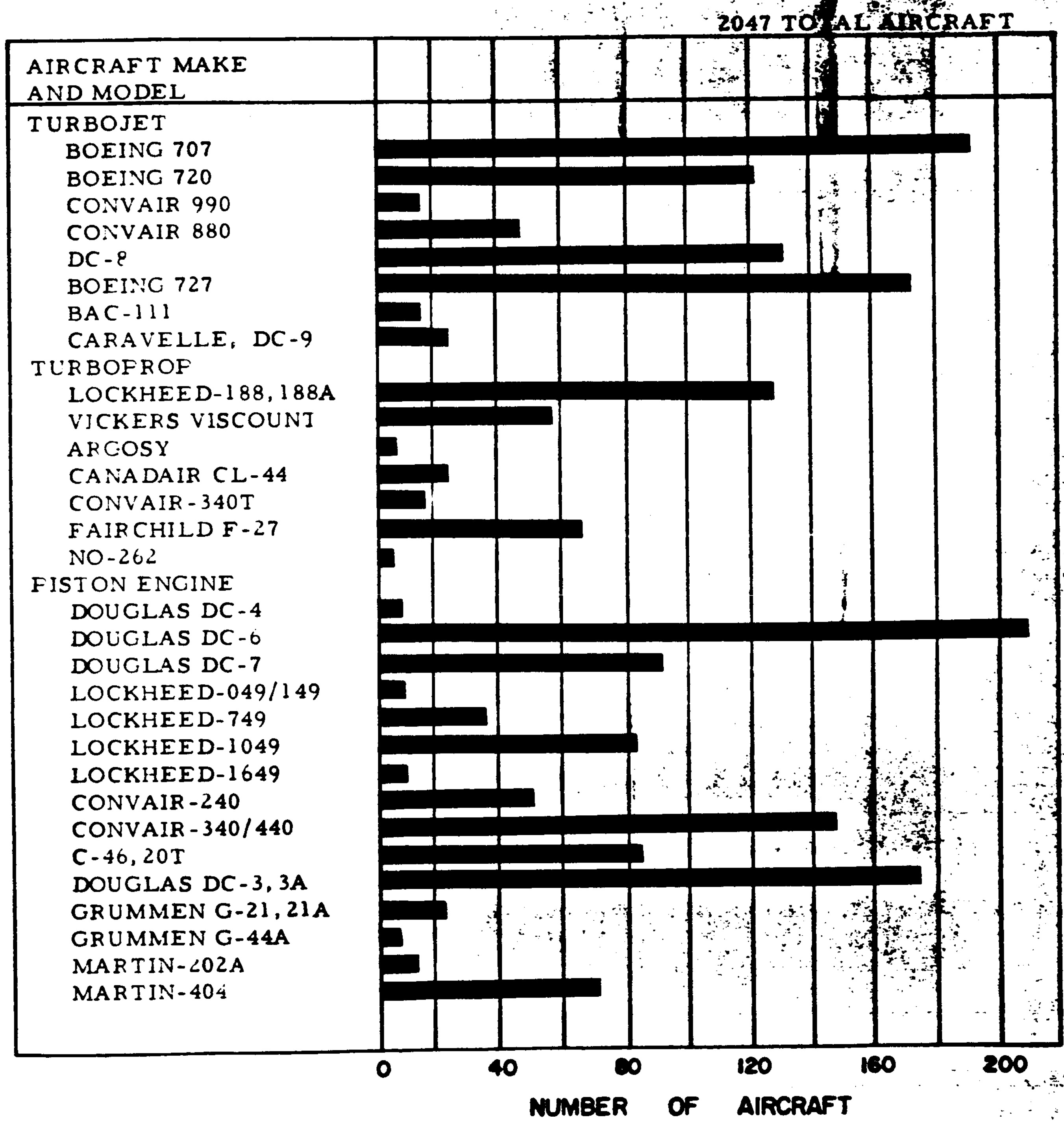


FIGURE 5-2

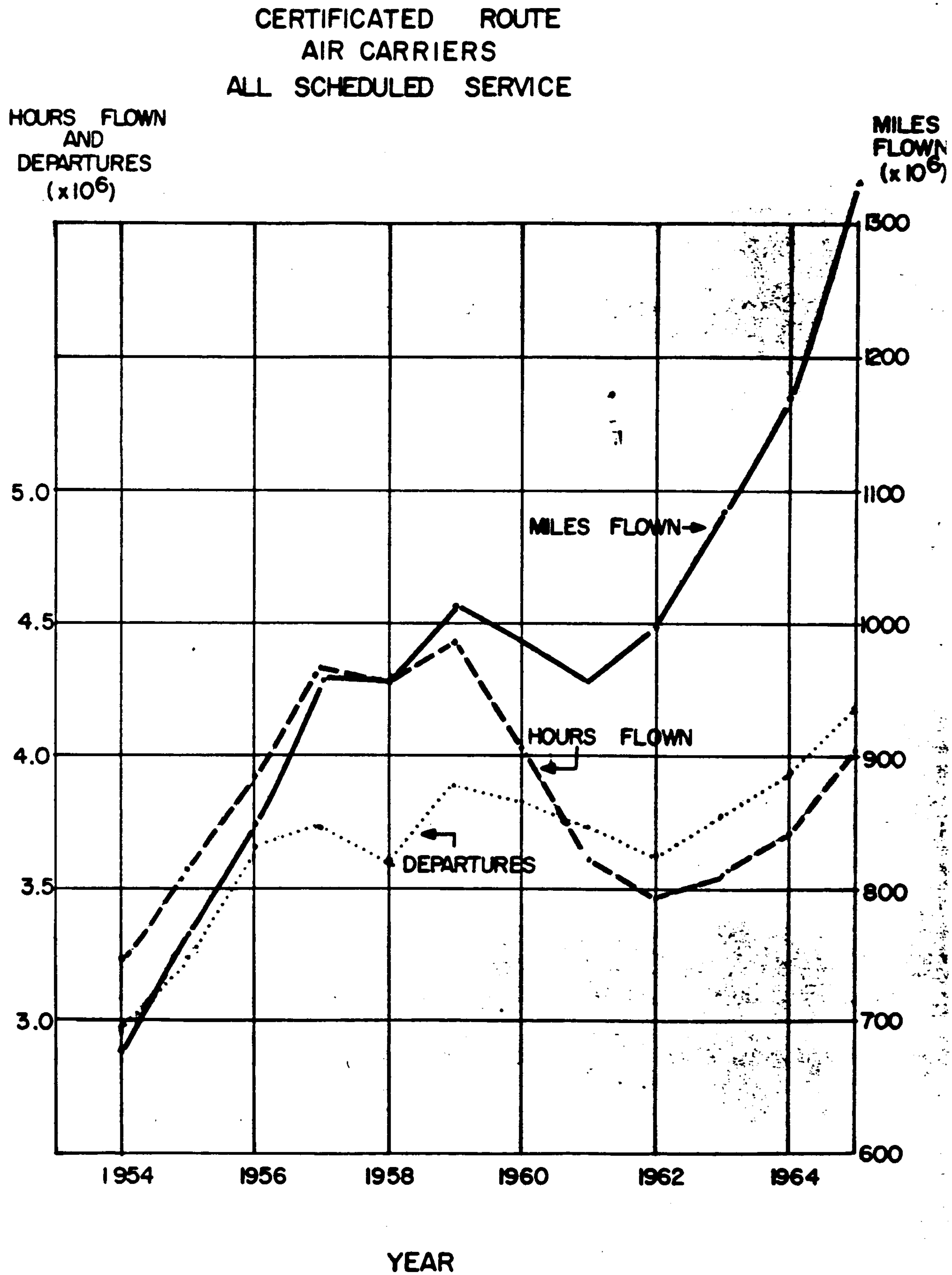

CERTIFICATED ROUTE
AIR CARRIERS
ALL SCHEDULED SERVICE
HOURS FLOWN AND DEPARTURES (x10^6)
MILES FLOWN (x10^6)
5.0
4.5
4.0
3.5
3.0
1300
1200
1100
1000
900
800
700
600
MILES FLOWN
HOURS FLOWN
DEPARTURES
1954
1956
1958
1960
1962
1964
YEAR

FIGURE 5-3

CERTIFICATED PASSENGER/CARGO
U.S. DOMESTIC & INTERNATIONAL AIR CARRIERS
OPERATIONS DATA

(REF. 1966 FAA STATISTIC HANDBOOK)

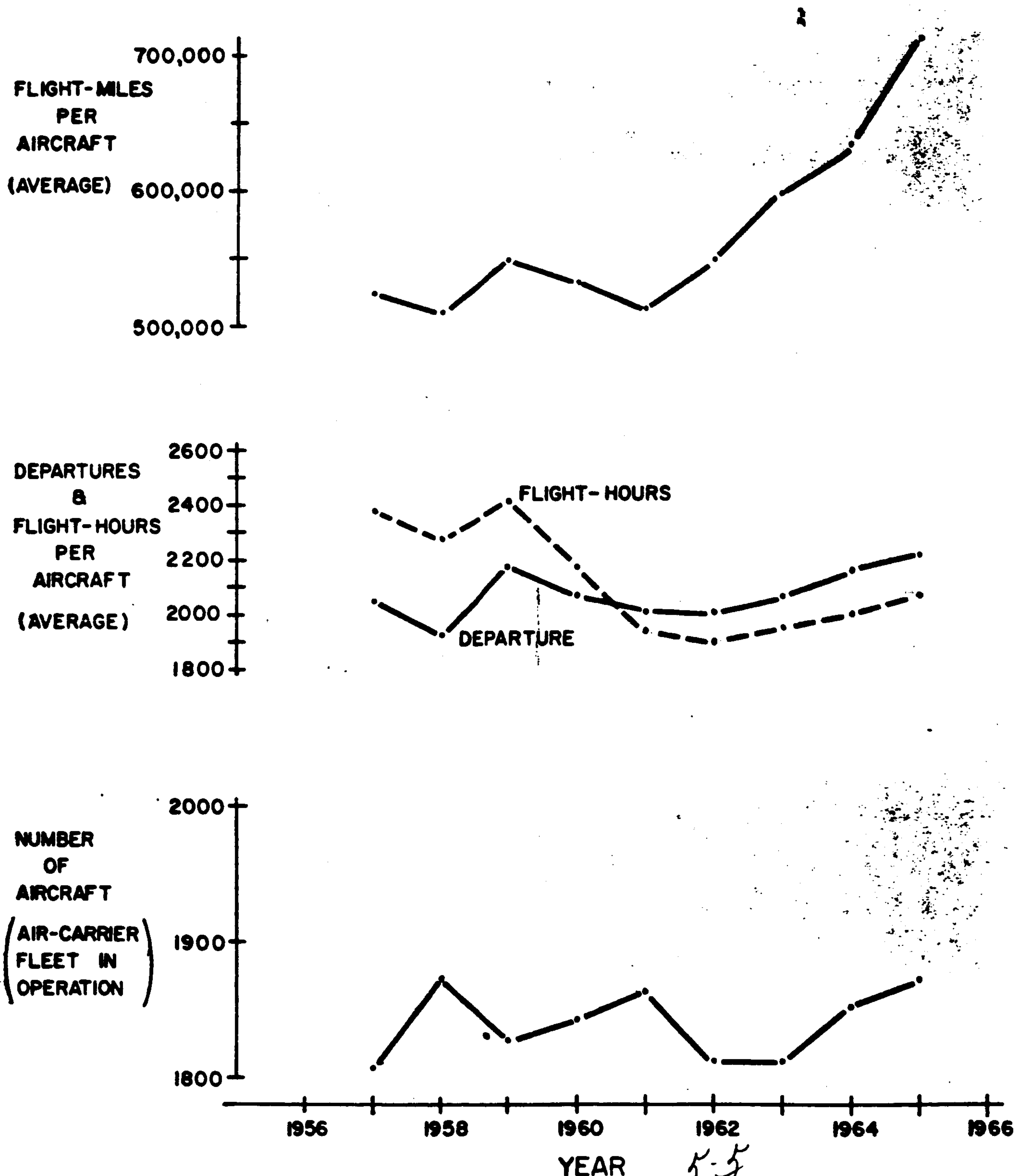
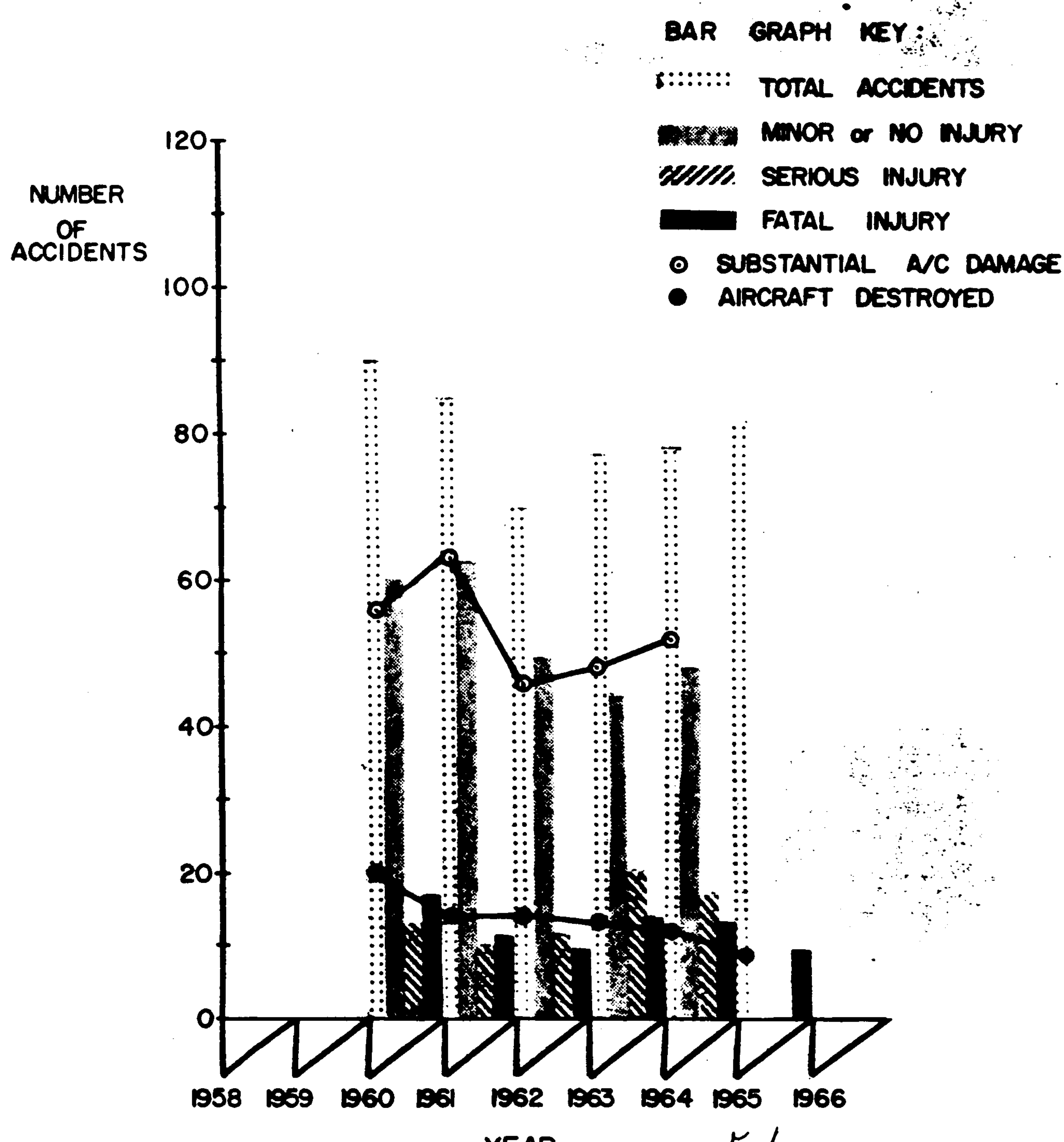


FIGURE 5-4

U.S. CERTIFIED ROUTE AIR CARRIERS

ALL OPERATIONS - NUMBER OF ACCIDENTS



5-6

FIGURE 5-5

U.S. AIR CARRIERS
ALL OPERATIONS
FATALITIES PER FATAL ACCIDENT

1960–1965 INCLUSIVE

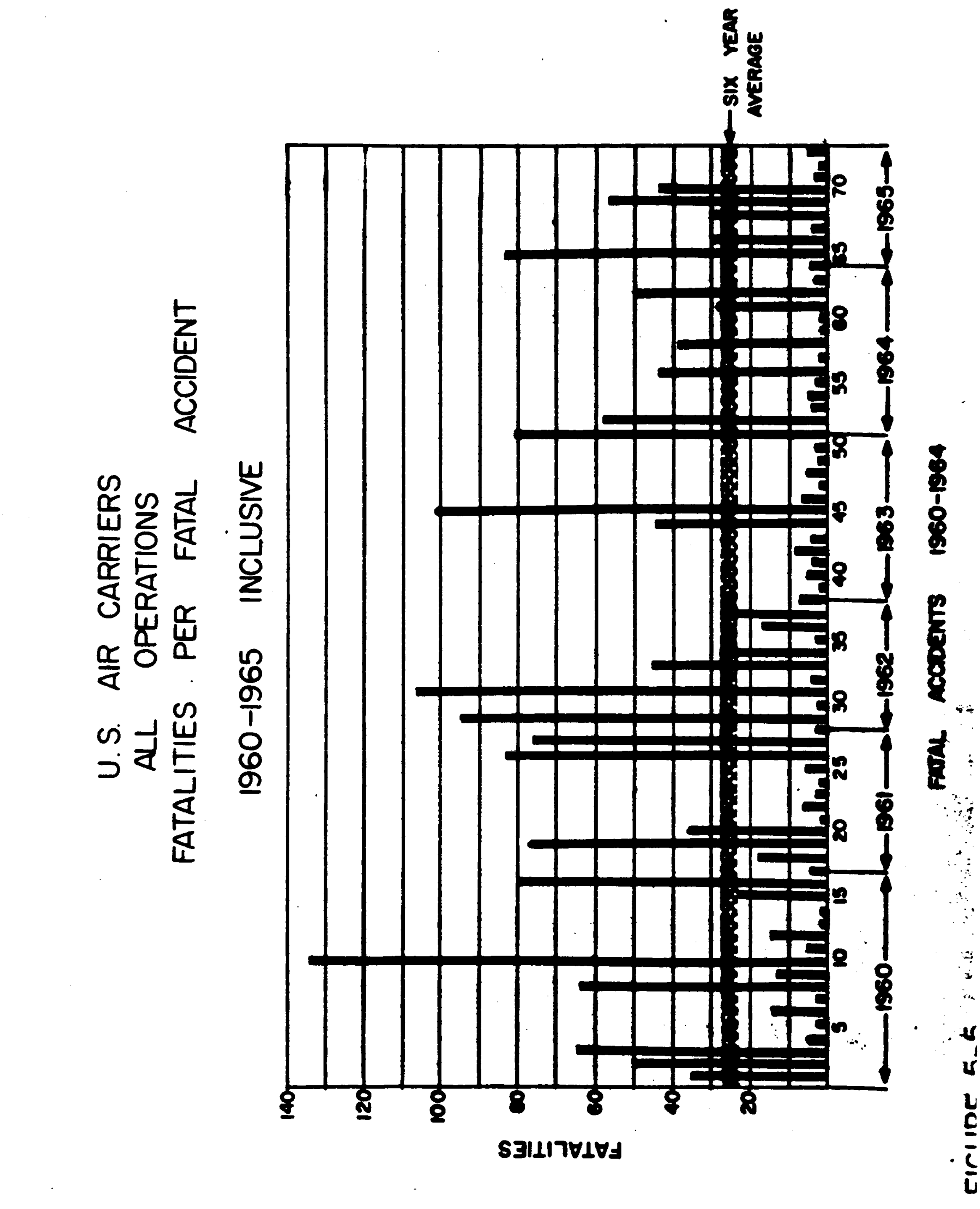
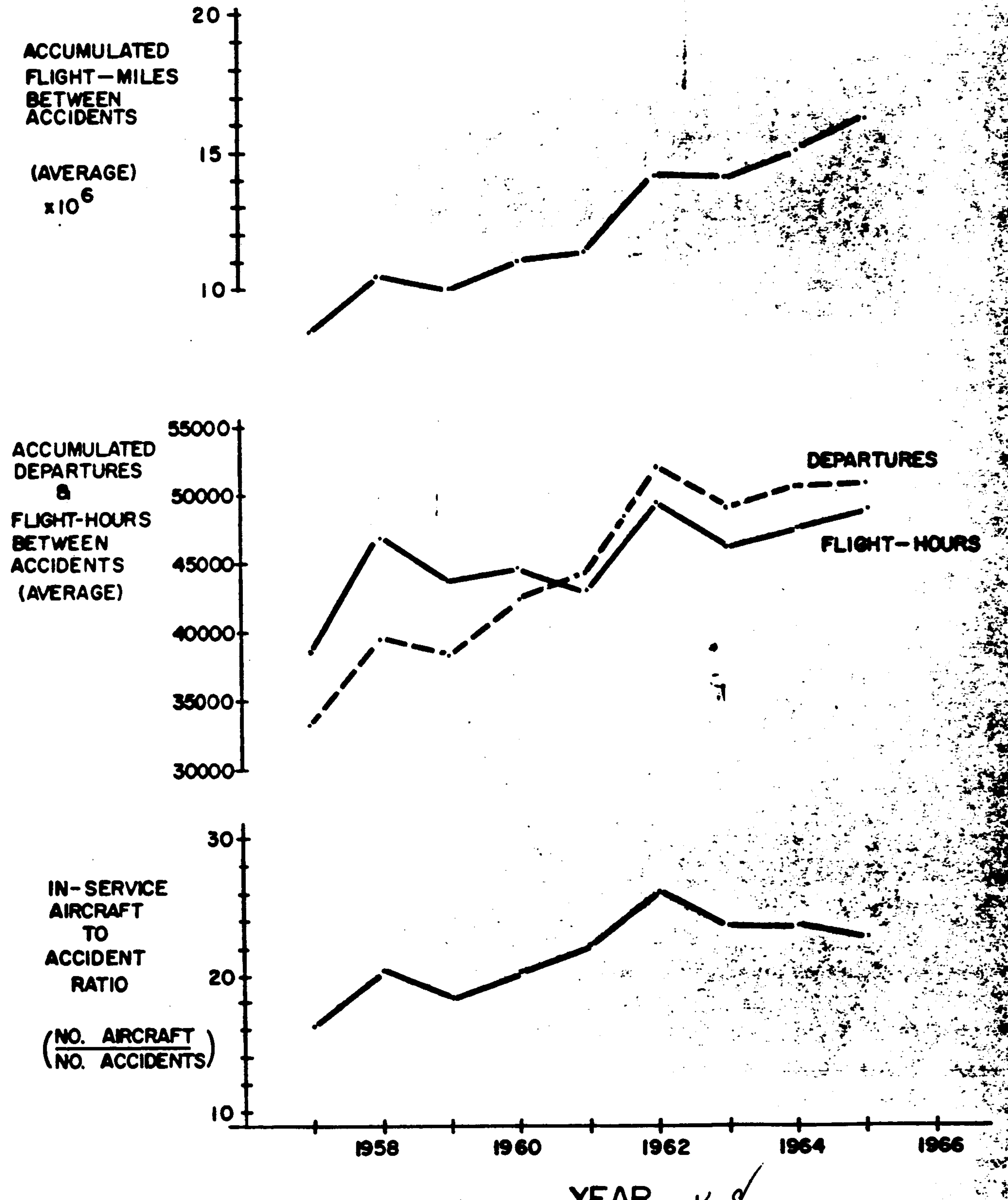


FIGURE 5-6

CERTIFICATED PASSENGER/CARGO
U.S. DOMESTIC & INTERNATIONAL AIR CARRIERS
ACCIDENT RATE DATA



U.S. AIR CARRIER ACCIDENTS
1960-1964 INCLUSIVE

FIGURE 5-7

402 ACCIDENTS   64 FATAL ACCIDENTS   1642 FATALITIES

PHASE OF OPERATION			ACCIDENTS PER PHASE	PERCENTAGE OF ALL ACCIDENTS	FATAL ACCIDENTS	FATAL ACC. % PER PHASE	FATALITIES
STANDING	2.9%	GROUND	14	3.5	1	7.14	2
TAKE-OFF TAXI	4.0	TAXIING	20	4.9	2	10.0	2
TAKE-OFF RUN	4.7	TAKE-OFF	56	13.9	12	21.4	404
INITIAL CLIMB	7.6						
CLIMB TO CR.	3.5	ENROUTE	106	26.4	29	27.36	972
ENROUTE CRUISE	14.5						
ENROUTE DESCENT FROM CRUISE	6.9						
APPROACH	11.8	LANDING	204	50.8	20	9.8	262
LEVEL OFF & TOUCHDOWN	13.8						
GO-AROUND	2.2						
ROLL-OUT	18.1						
TAXIING FROM LANDING	4.0						
OTHER	6.0	UNKNOWN	2	.5	0	0	0
TOTALS			402	100%	64		1642

6.0 GENERAL AVIATION ACCIDENT STATISTICS (Rotorcraft Excluded)

U.S. General Aviation includes all domestic civil flying other than scheduled and related flying of public airlines. Over the past several years the annual flying time of planes in general aviation has been about four times the flying time of public carriers in their domestic operations.

General aviation flying is categorized by five types: pleasure, business, aerial application, instruction and commercial (excluding aerial application) and miscellaneous.

Of all types of general aviation flying, pleasure flying accounted for about 25% of the total hours and for one-half of the pilot fatalities in the 1962-63 period.

The second highest accident mortality rate is experienced in commercial (air taxi service, fire control activities, etc.) and miscellaneous flying. While the time spent in commercial flying is nearly the same as in pleasure flying, the actual number of deaths was only about one third that of pleasure flying.

Business flying has experienced a somewhat better accident record than commercial flying. Business flying, which utilizes company-owned aircraft to transport executives, sales personnel, etc., accounts for roughly two-fifths of the total flying time in general aviation. In 1962-63 the fatality rate for business flying was 3.5 per 100,000 plane hours, or about two-fifths lower than for general aviation as a whole.

The instructional flying category consists of flight training of civilians under accredited instructor supervision. One-sixth of the total flying time was accounted for by instructional flying in 1962-63. However, this type flying was responsible for only one-twentieth of all fatalities.

General Aviation data presented in the remainder of this section are for all flying categories and for all types of aircraft.

General aviation currently consists of over 90,000 aircraft of all types. This is twice the number of only ten years ago and the rapid growth continues. Figure 6-1 graphically portrays this rapid growth. Out of these aircraft, about one in 18 can be expected to have an accident of some type; one aircraft in 25 can be expected to receive substantial damage; one aircraft in 90 can be expected to be destroyed; and about one aircraft in 180 can be expected to sustain fatalities. The record of general aviation (Figure 6-1) shows that an accident occurs for every 4000 hours of accumulated flying time while the commercial air carrier record averages 50,000 flying hours between accidents.

Figure 6-2 shows the number of accidents currently at 5000 per year, of which 500 are fatal, and 1000 aircraft are destroyed. The actual number of fatalities has increased to over 1000 per year in apparent proportion with the increased number of aircraft. The rapid upward trend is shown in Figure 6-3.

A breakdown of general aviation accidents by phase of operation for the year 1963 is shown in Figure 6-4. It is readily apparent that the largest single percentage of accidents occur during landing; however, only a small number of these end with fatalities. Most of the fatalities occur during normal cruise, or other in-flight conditions associated with bad weather, malfunction of systems, pilot error or unexpected collision. No means of escape is provided in modern-day aircraft for in-flight emergencies. The high velocity condition associated with in-flight emergencies would and does in fact provide reason for such a high ratio of mortality in this phase.

FIGURE 6-1

GENERAL AVIATION — ALL TYPES AIRCRAFT

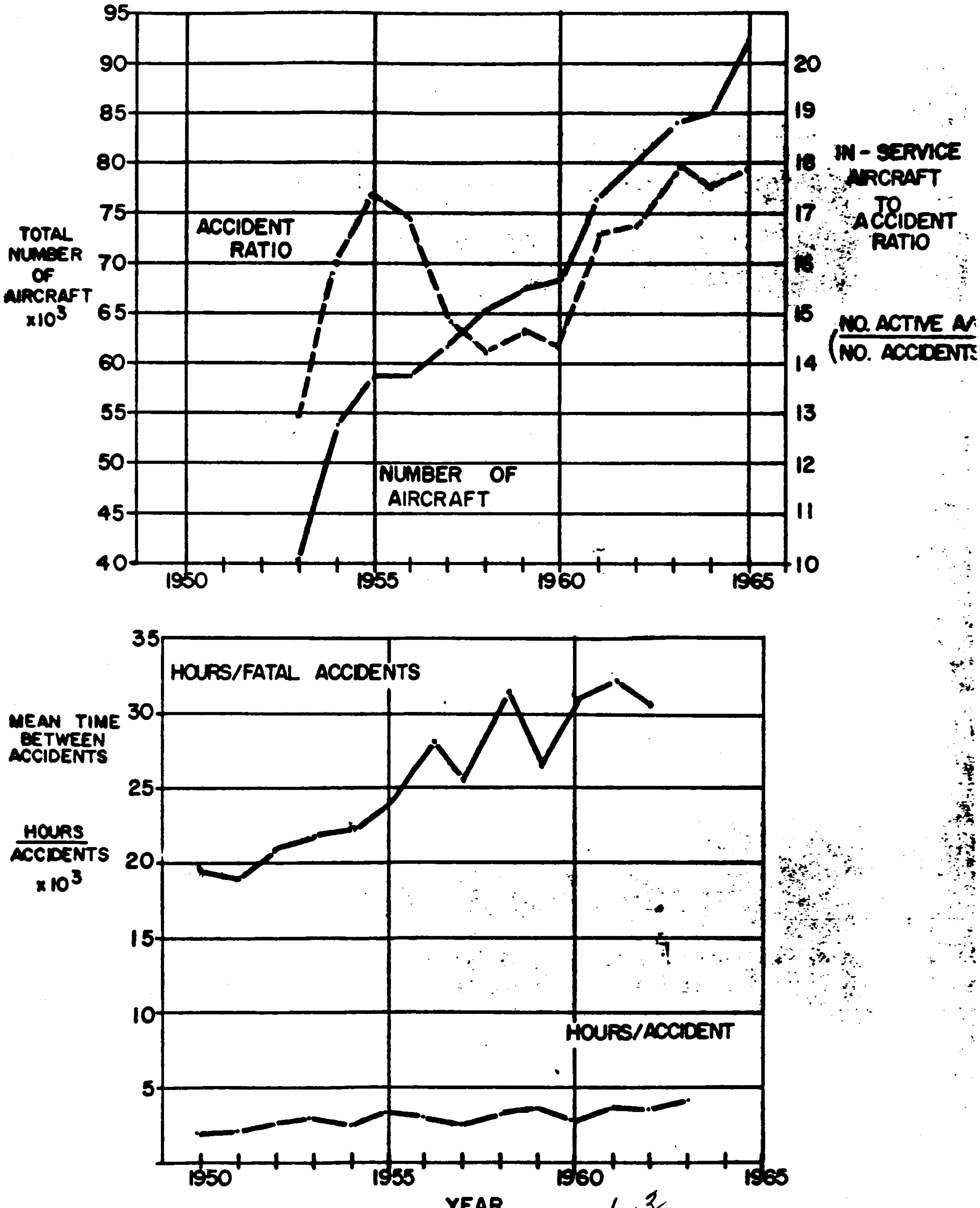
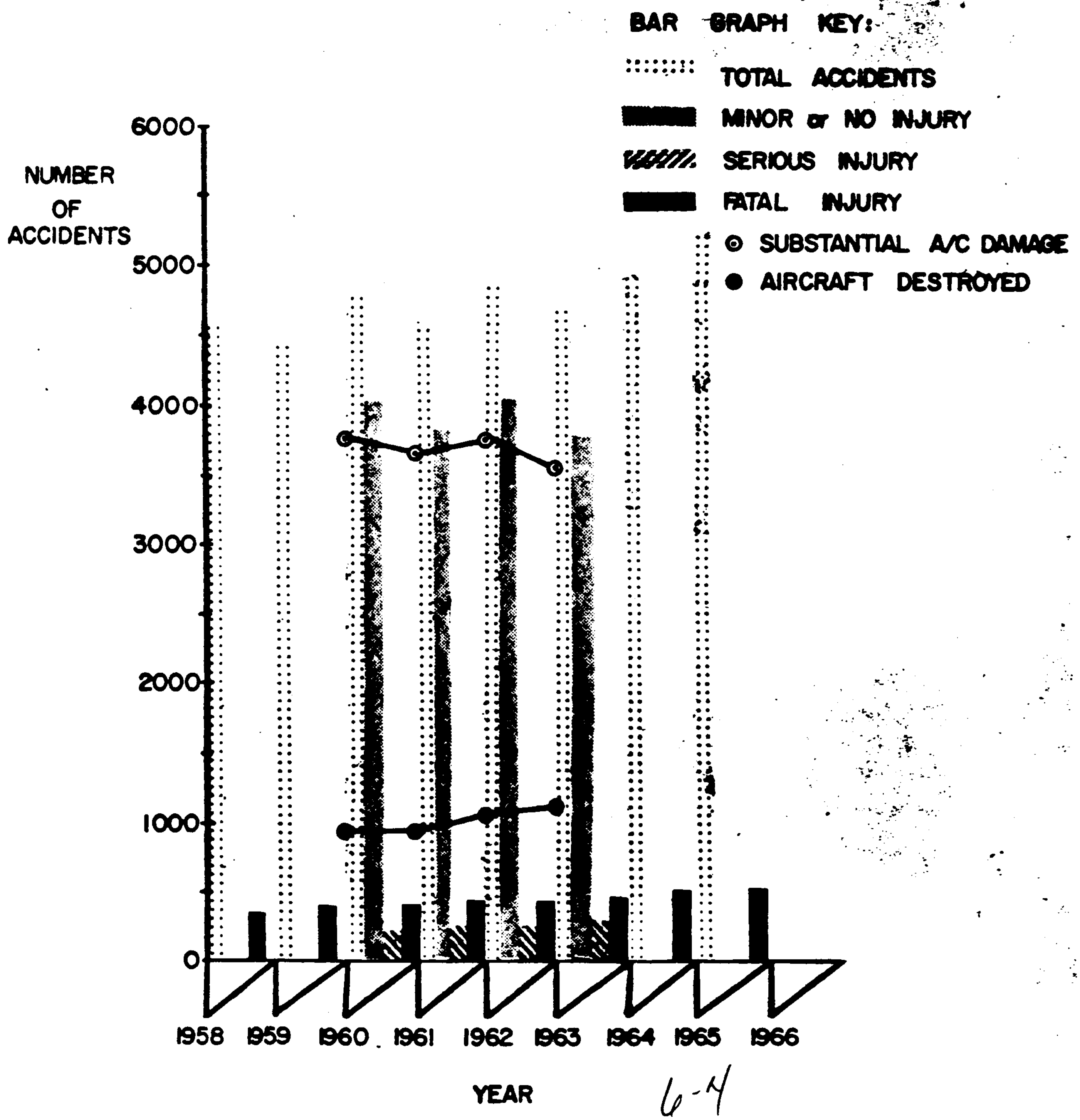


FIGURE 6-2

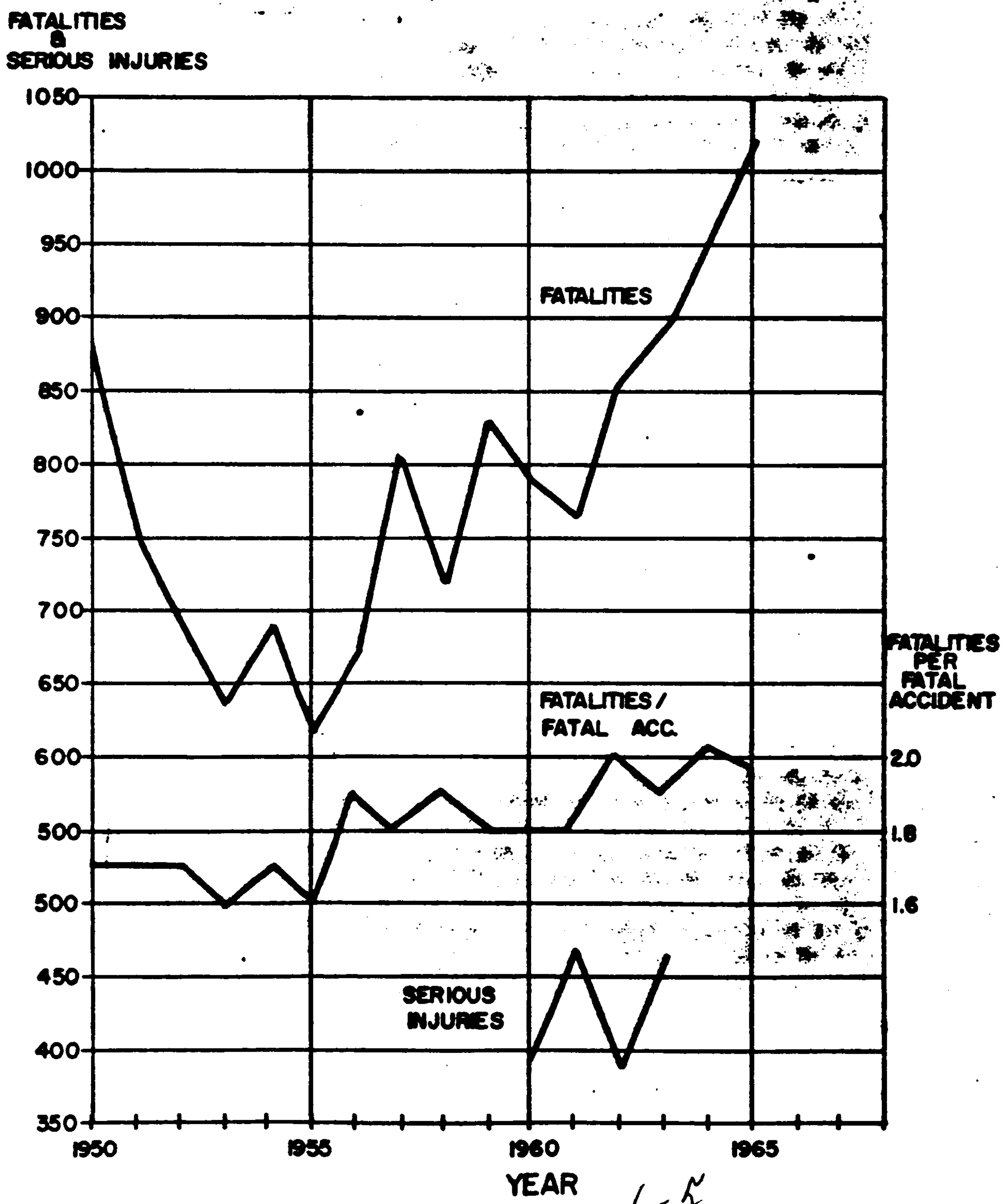
GENERAL AVIATION

ALL OPERATIONS - NUMBER OF ACCIDENTS



6-4

GENERAL AVIATION
ACCIDENT STATISTICS



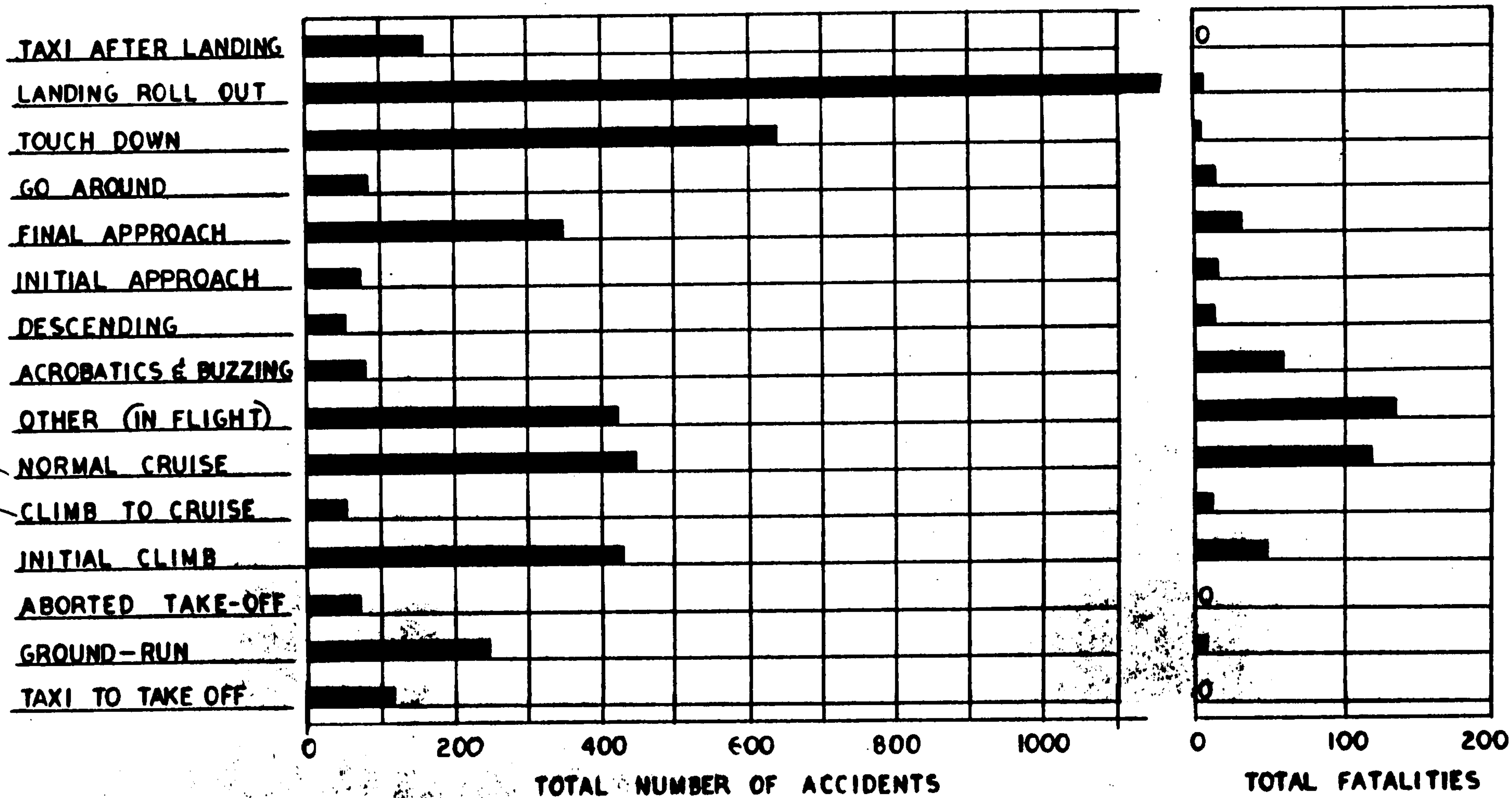
GENERAL AVIATION-ALL OPERATIONS
(63300 ACTIVE AIRCRAFT)

TYPICAL DISTRIBUTION OF ACCIDENTS BY PHASE-YEAR 1963

4690 ACCIDENTS—462 FATAL—295 WITH SERIOUS INJURY—3913 WITH MINOR INJURY

1097 AIRCRAFT DESTROYED—3550 AIRCRAFT SUBSTANTIALLY DAMAGED—43 MINOR DAMAGE

893 FATALITIES—462 SERIOUS INJURIES—7336 MINOR INJURIES



6-6

FIGURE 6-

7.0 ROTORCRAFT ACCIDENT STATISTICS

The purpose of the statistics presented in this section is to provide general aviation rotorcraft accident data for the four-year period of 1960 through 1963. The statistics are taken from the CAB report "Statistical Review of Rotorcraft Accidents, U.S. General Aviation, 1960-1963."

Figure 7-1 shows a 3-fold increase in the number of general aviation operational helicopters over the period from 1959 to 1965.

Two factors are evidenced in Figure 7-1. One out of every 6 rotorcraft have been involved in some type of accident for the five-year period reported, and as of 1963 there was one helicopter accident recorded for about every 2100 in-service hours. These statistics are better understood when compared to the U.S. commercial aviation experience of 1 accident per 50,000 in-service hours in 1966 and general aviation fixed wing rate of one accident per 4000 hours.

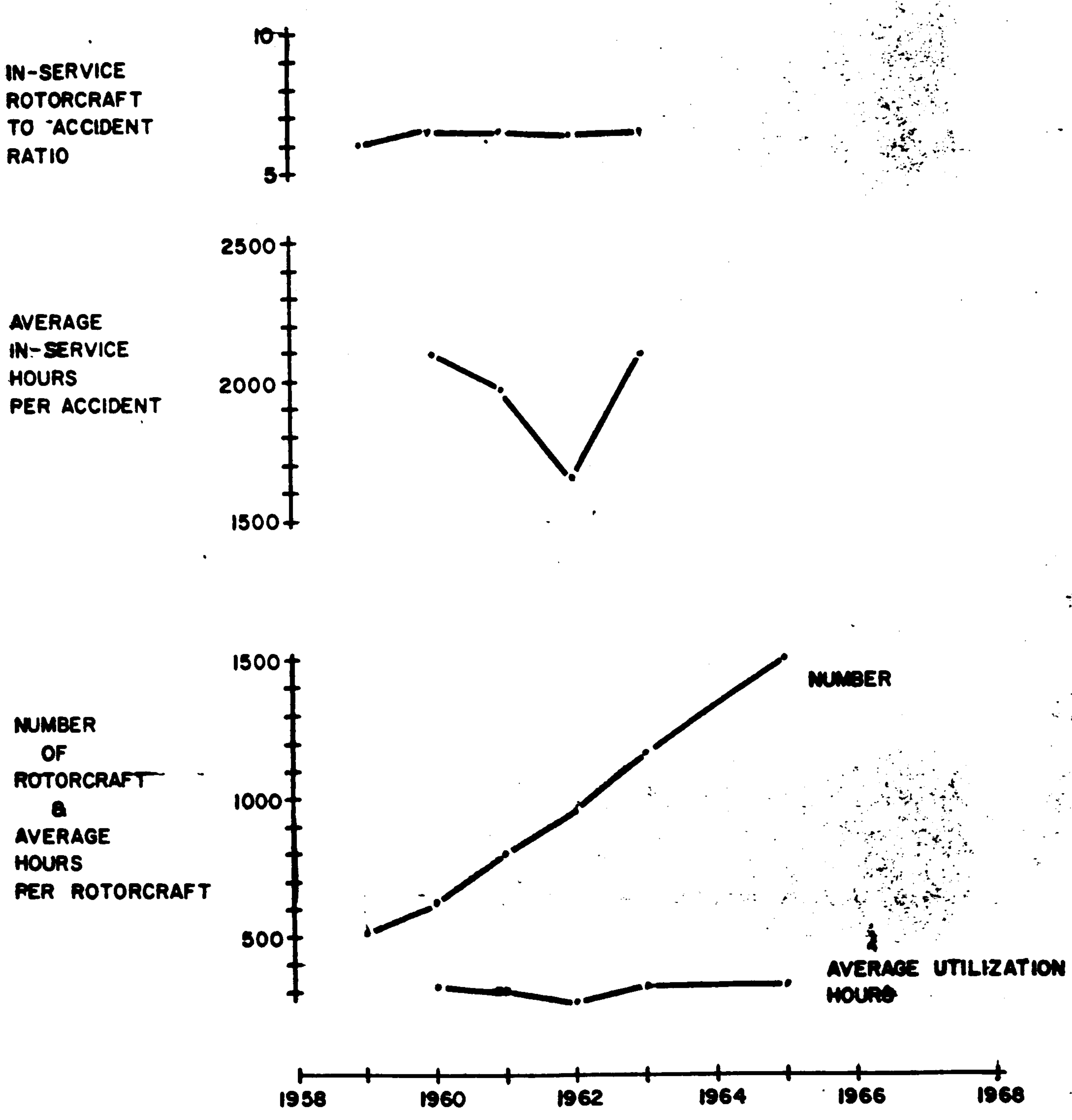
Figure 7-2 shows the relative increase in fatal, serious, and minor or no injury rotorcraft accidents from 1960 to 1963. As noted, the fatal and serious injury types of accidents did not increase greatly for the four years, but the minor or no injury accidents greatly increased.

Figure 7-2 also shows a plot of rotorcraft damage versus years. When compared with the injury graph it is seen that the number of destroyed rotorcraft is nearly twice the number of fatal or serious injury accidents.

Figure 7-3 gives a breakdown of the helicopter accidents by phases.

FIGURE 7-1

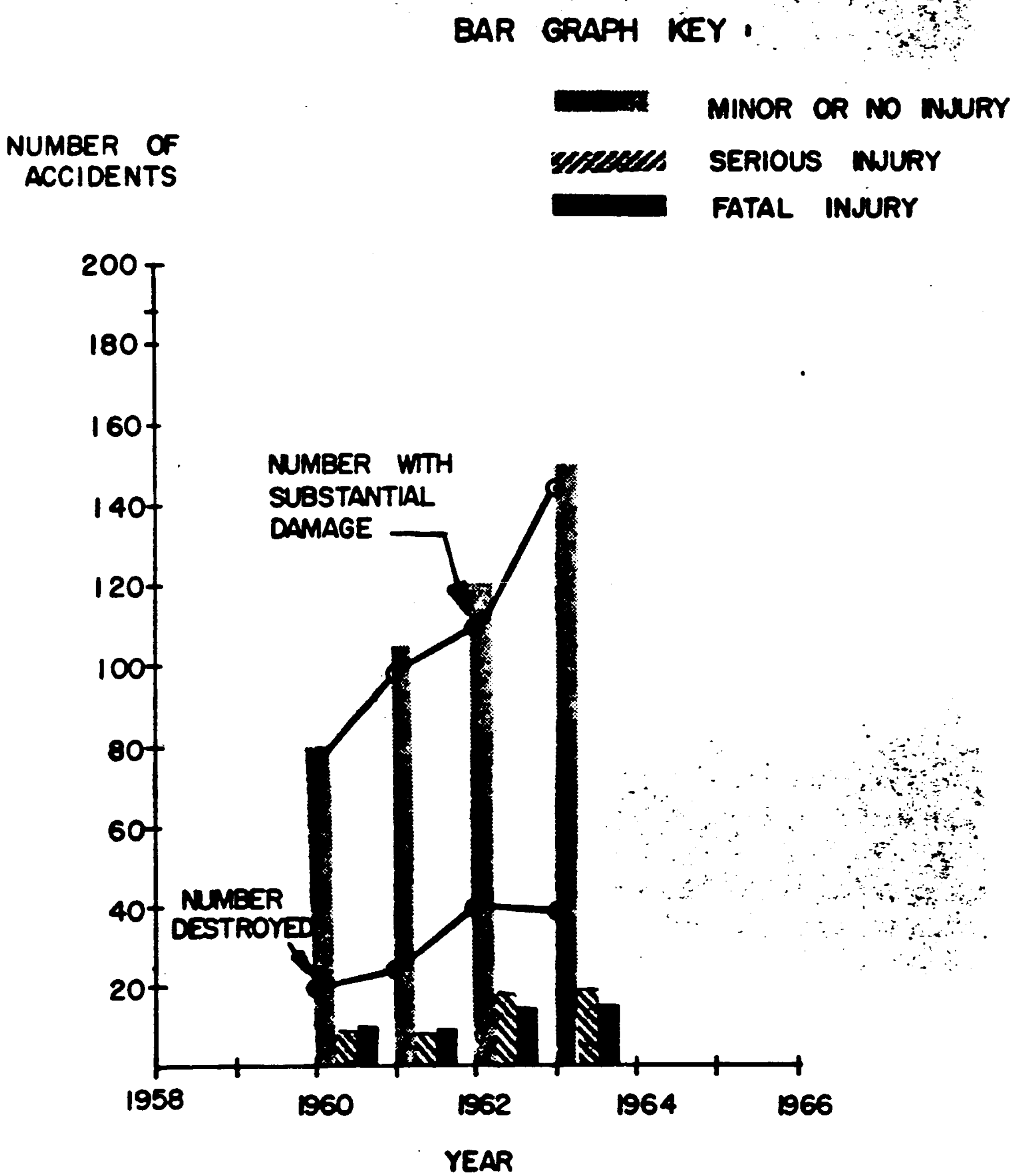
U. S. GENERAL AVIATION ROTORCRAFT STATISTICS & ACCIDENT DATA



GENERAL AVIATION ROTORCRAFT

(REF. BOSR 14-4-1, 1960-1963)

ACCIDENT STATISTICS



U.S. GENERAL AVIATION

ROTORCRAFT ACCIDENTS

1960-1963 INCLUSIVE

559 ACCIDENTS | 50 FATAL ACCIDENTS | 72 FATALITIES

Sub-phase	%	Phase of Operation
Idling Rotors	3.9%	Static
Aerial Taxi	2.1	Taxi
Ground Taxi	1.3	Takeoff
Initial Climb	4.5	Takeoff
Vertical	7.3	Takeoff
Running	1.4	Takeoff
Aborted	1.3	Takeoff
Other	1.1	Takeoff
Normal	16.8	Inflight
Hovering	6.6	Inflight
Descending	3.6	Inflight
Other	10.6	Inflight
Approach	6.8	Landing
Level-Off, Touchdown	18.9	Landing
Power-on Vertical Landing	5.4	Landing
Power-Off Auto.	6.9	Landing
Other	1.1	Landing
Unknown	.4	Landing
TOTALS	100.0%	

Phase of Operation	Accidents Per Phase	Percentage of All Accidents
Static	22	3.9
Taxi	12	2.1
Takeoff	94	16.9
Inflight	210	37.6
Landing	221	39.5
TOTALS	559	100.0%

8.0 MILITARY ACCIDENT STATISTICS

The USAF ejection data presented are taken from "USAF Ejection Experience, 1 January 1961 - 31 December 1963" by R. H. Shannon and S. P. Chunn, Major, USAF (MC).

During the 3 year period noted above, ejection seats were used 601 times for in-flight escape from disabled USAF aircraft. Five hundred and one, or 83% of the total ejections were successful (non fatal). In 17% (100) of all ejections, the crew members received fatal injuries.

As can be seen from Figure 8-1, total ejections and the ejection rate per 100,000 flying hours showed a marked year-to-year decrease. Figure 8-1 also shows the number of ejections and the percentage of successful ejections versus years. The year 1959 was the best year for USAF ejections with an 88% success rate. Since this 1959 peak the success rate for all ejections has decreased only slightly; however, the rate of non-fatal ejections below 1000 feet has been poorer. Ejection seat-instability problems associated with rocket assist and c.g. offset make low level ejection critical. A stabilized seat is therefore necessary at low attitudes. Safer means of low level ejection are needed and in recent years have been receiving major attention. The incorporation of zero/zero recovery systems and seat stabilization devices is increasing. Engine failure and loss of control were the primary causes of emergencies which resulted in escape by ejection. Figure 8-2 shows that most fatalities resulted after these two types of emergencies were experienced. At low altitudes and low speeds, both engine failure and loss of control cause conditions which are unfavorable for successful ejection.

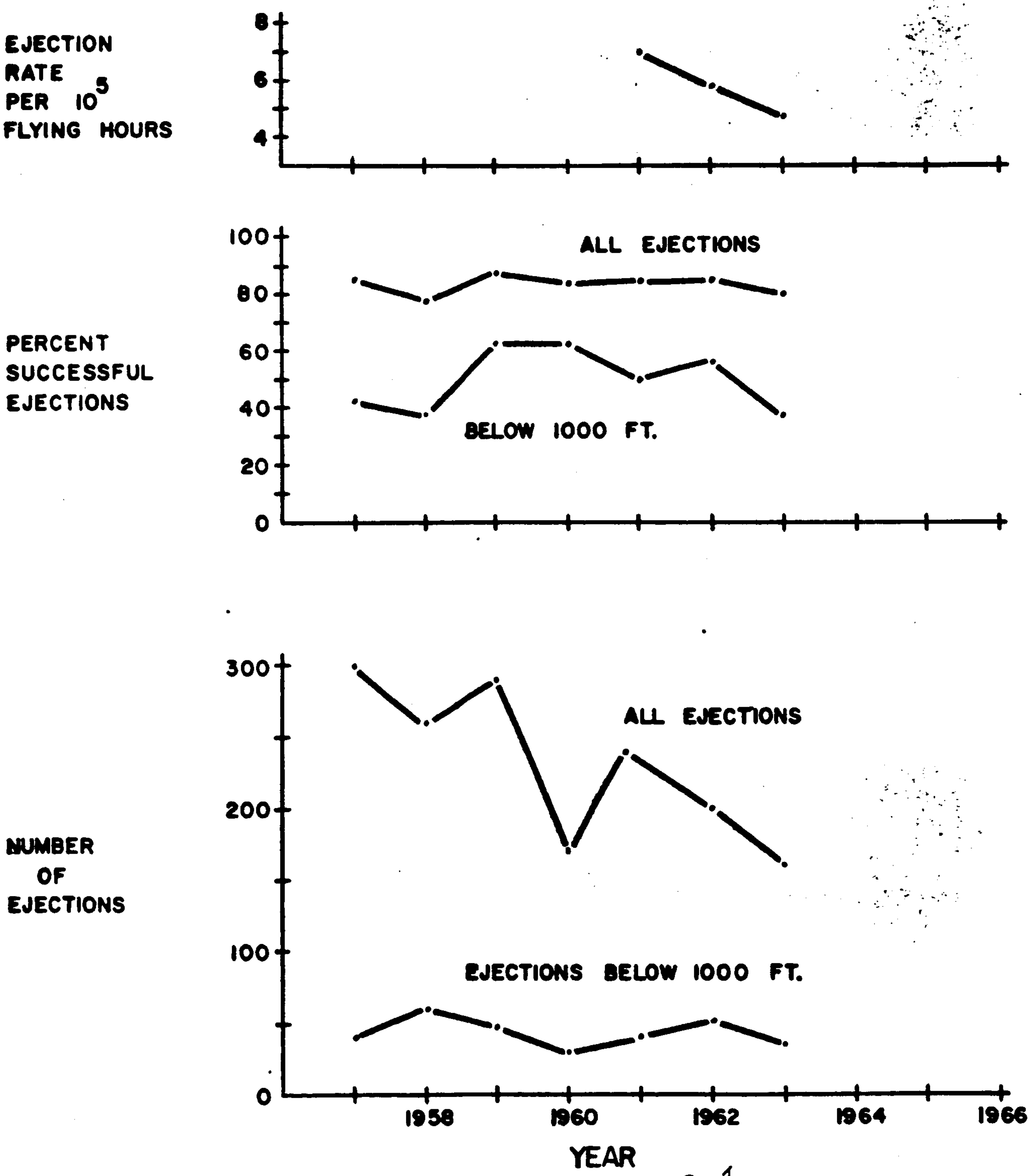
The primary factor in determining the success or failure of an ejection is the altitude, attitude, and airspeed. As can be seen from Figure 8-3, 72 of all ejections occurred at an altitude of less than 500 feet. Fifty seven percent of the fatal ejections resulted from the 72 low-level attempts. Although higher performance aircraft have been introduced in the last few years, statistically the speed at the time of ejection has not increased.

Approximately 218 knots was the average IAS for all ejections in the 1961-1963 period. This bar chart also shows that over half of all ejections were performed in a level or climbing attitude. About 59% of the ejections attempted below 1000 feet, in which a descending or other unfavorable aircraft attitude was reported, resulted in fatalities.

Finally, from Figure 8-4 it is noted that 73 of the 100 total fatalities resulted from violent impacts with the ground or water usually after an attempted low-level escape. This cause of death factor again points out the need for a true zero/zero escape system.

FIGURE 8-1

U.S.A.F. EJECTION EXPERIENCE 1957-1963 INCLUSIVE



USAF EJECTIONS
TYPE EMERGENCY PRECIPITATING EJECTION
1961–1963 INCLUSIVE
601 TOTAL EJECTIONS

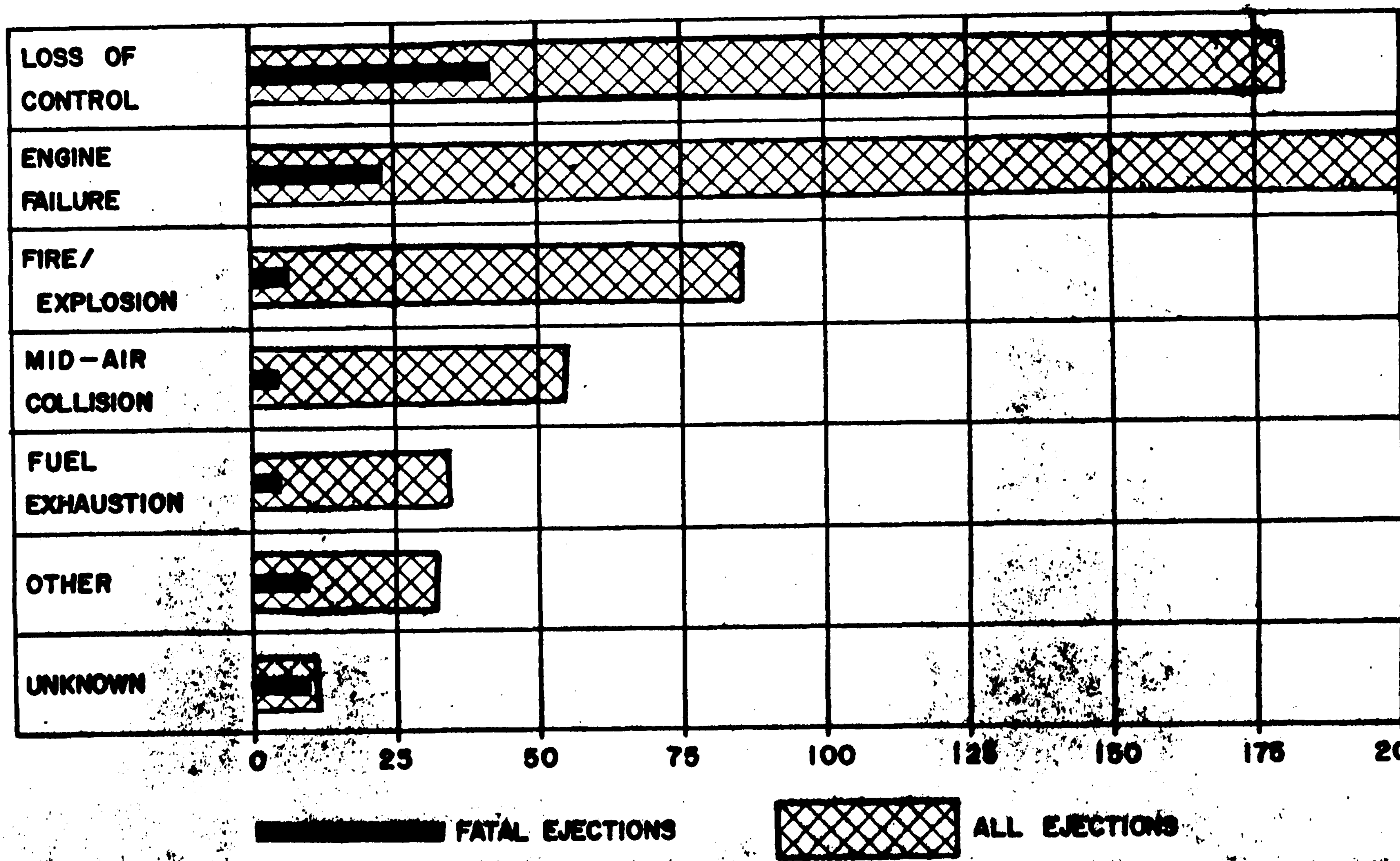


FIGURE 8-

8-4

FIGURE 8-3

USAF

PRIMARY CAUSE OF FATAL EJECTIONS

1961–1963 INCLUSIVE

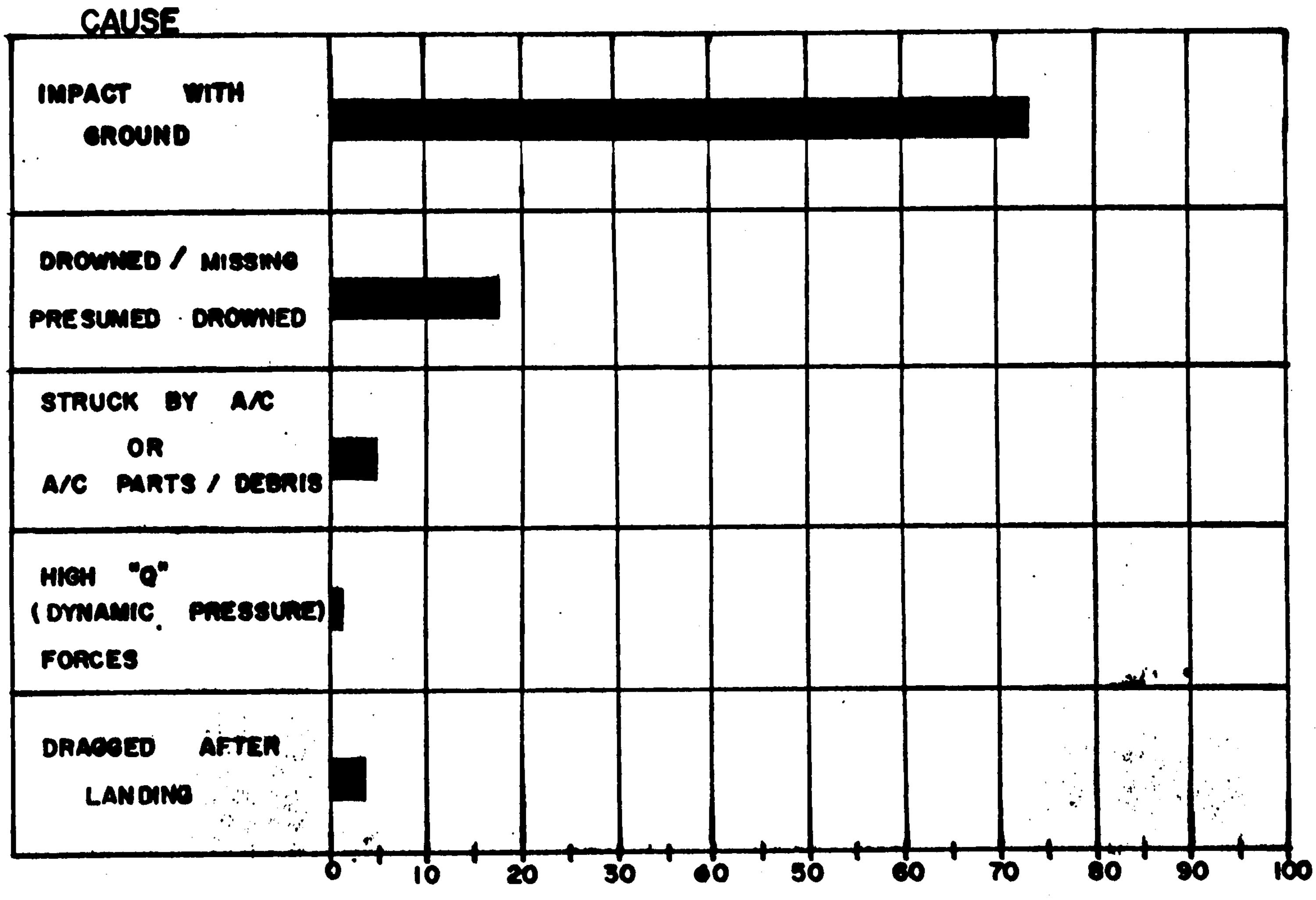
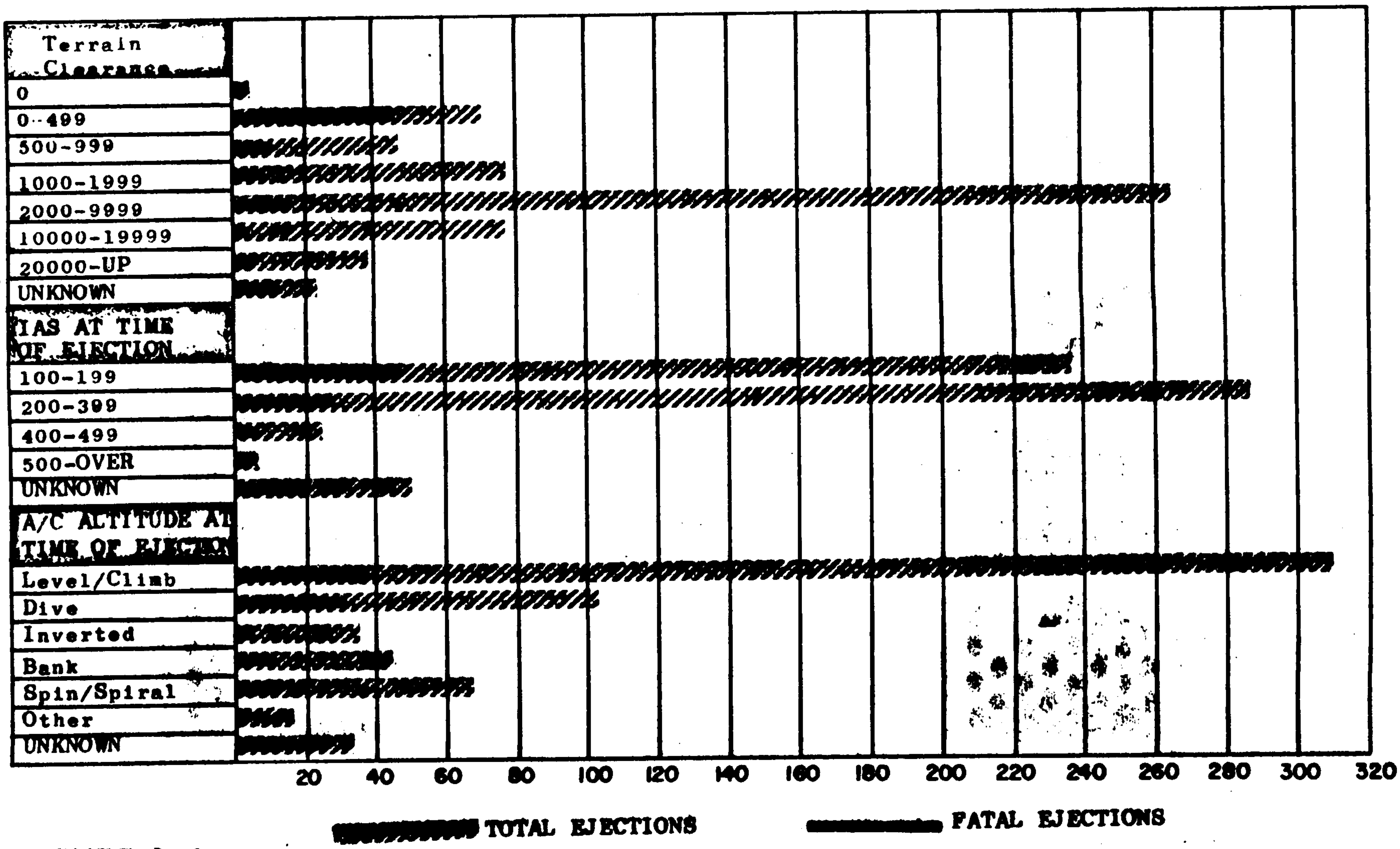


FIGURE 8-3

USAF EJECTIONS PER TRIAD
OF ALTITUDE, AIRSPEED, ATTITUDE
1961-1963 INCLUSIVE
601 TOTAL EJECTIONS
17% FATAL EJECTIONS
17% MAJOR INJURY
66% MINOR/NO INJURY



8-4

FIGURE 8-4

9.0 HUMAN TOLERANCES

This section presents a number of graphical data related to human tolerances for acceleration, impact, temperature and decompression. These data were gathered from the NASA SP-3006 "Bioastronautics Data Book" and FAA reports AM 66-12, and AM 66-18 written by J. J. Swearingen, of the Civil Aeromedical Research Institute. These particular graphs have been selected because of their direct relationship to aircraft accident survival.

The graphs in this section are provided mainly as supplementary data and are occasionally referred to as part of the concept analysis and evaluation.

An analogy of the human body is a series of spring-mass-damper systems. In such a model, the rate at which acceleration is applied as well as the maximum acceleration are inferred to be of great importance in describing body deceleration.. The physical relationship of these parameters indicate compromises that might be made between the two for an available stopping distance.

Figure 9-8 shows the relationship of maximum acceleration and onset rate for stopping distances from 4 to 8 inches from a 30 ft./sec. impact velocity[11]. The most efficient use of stopping distance is produced by an infinite onset rate. This is represented by the minimum g, infinite onset point of each curve. A triangular time history is represented by the maximum g end point of each curve. The points between these two extremes represent trapezoidal time histories with specific onset rates and a finite crushing time at constant g. For protection of humans, the areas of high g and low onset rate are of interest. Superimposed on this figure are the approximate acceleration tolerances[10] for humans with acceleration duration time labeled for each data point.

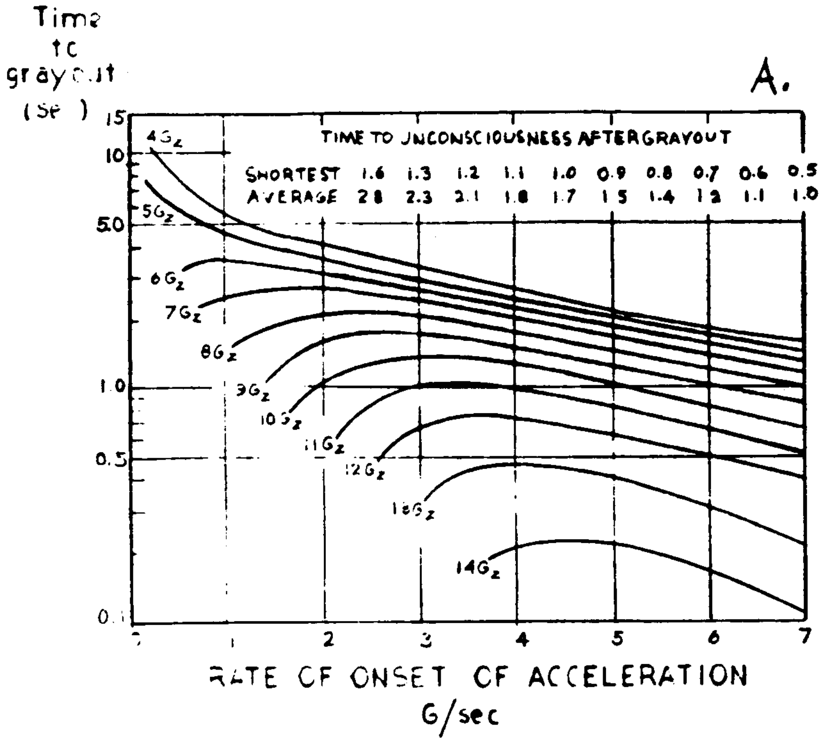
G being the peak loading and t the time duration of impact holds true. It is widely accepted that for impact durations of less than 0.07 seconds, the body acts as a rigid mass with no fluid shifts occurring[11]. Thompson assumed that structural limits for body tissue are in excess of 200 g and thus constructed the tolerance curve of figure 9-9. The magnitude of peak g may range up to 45 g for impacts of greater than 0.07 second duration, hence there is infinite slope for the tolerance curve in this area. For impacts of less duration time, up to about 200 g, the tolerance limit is represented by the criteria that 2 V = 100 (V = 50 fps) and for this area the tolerance curve is horizontal. The validity of this concept is indicated by the data points on figure 9.9.

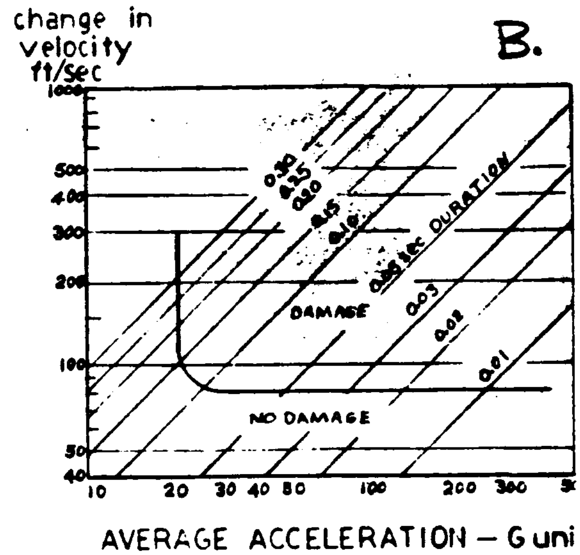
Based on these test results, and shown in Figure 9-10, A. B. Thompson states that the ultimate human limits to entire body impact is somewhere in the range of 45 and 55 psi impact force. The physiological shock yield point lies somewhere between 28 and 32 psi for transverse accelerations.

Body impact velocities as high as 45 fps may be expected in severe but survivable aircraft crashes.

The forehead can take over 200 g if it is applied to a contoured surface of 3 square inches or more[2.1].

ACCELERATION TOLERANCE





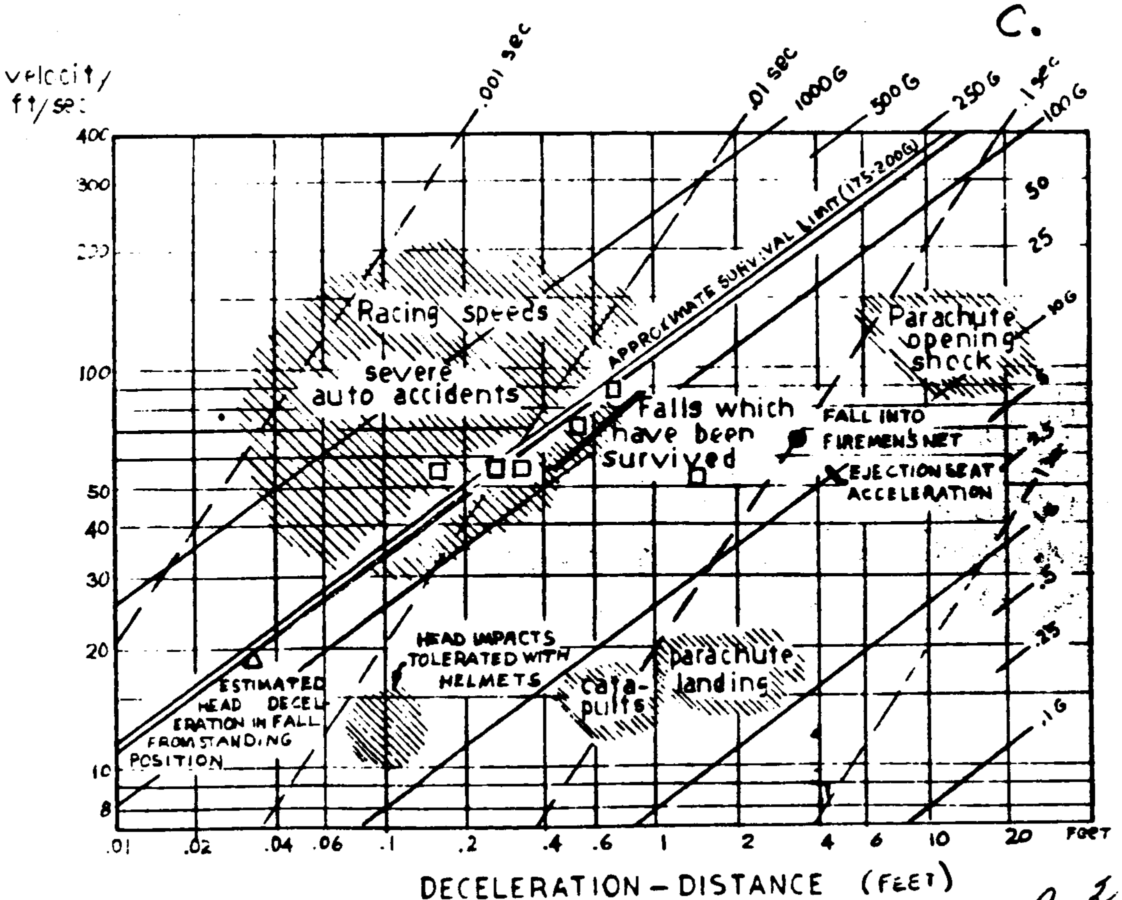


FIGURE 9

ABPUPT LONGITUDINAL DECELERATIONS

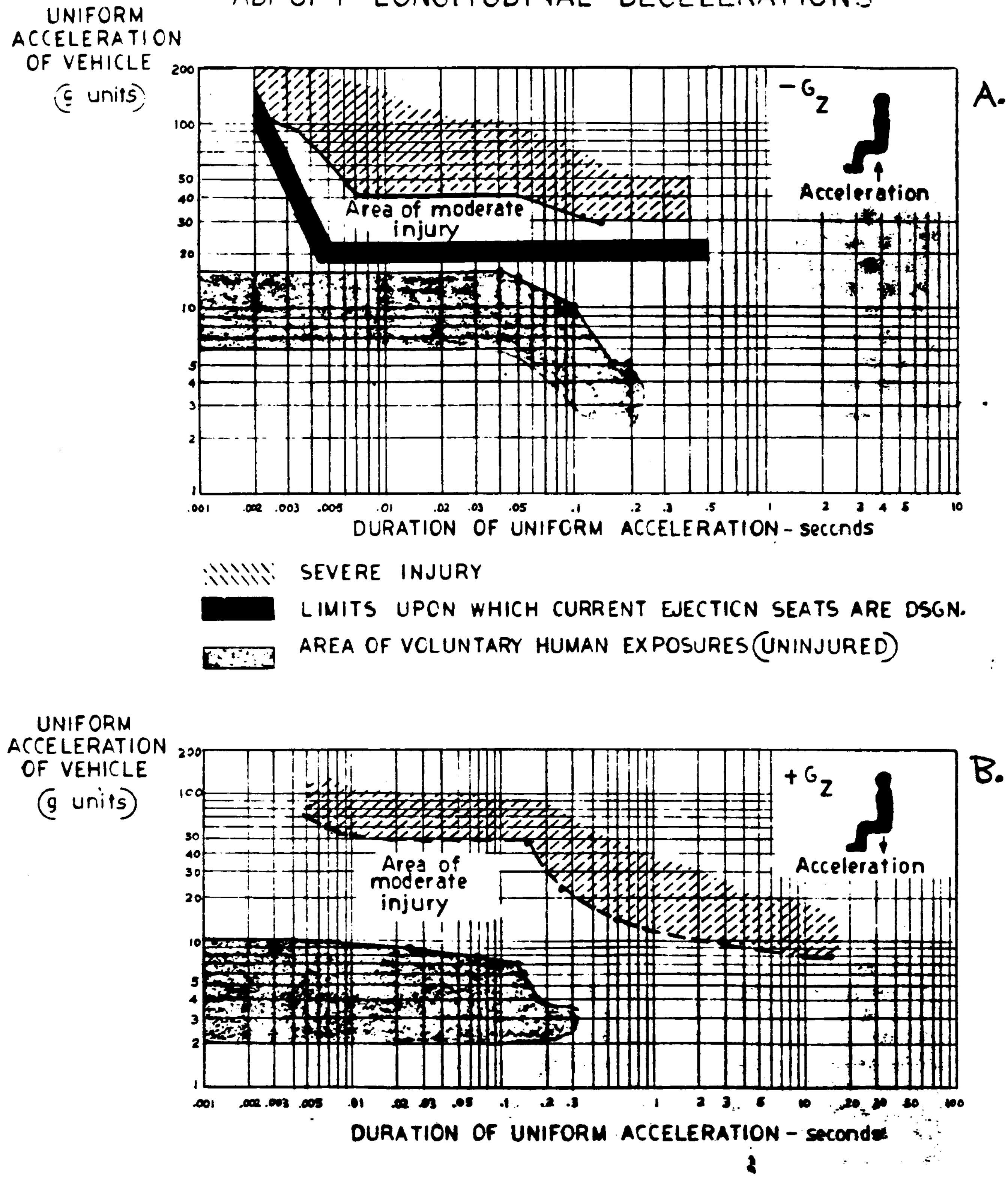
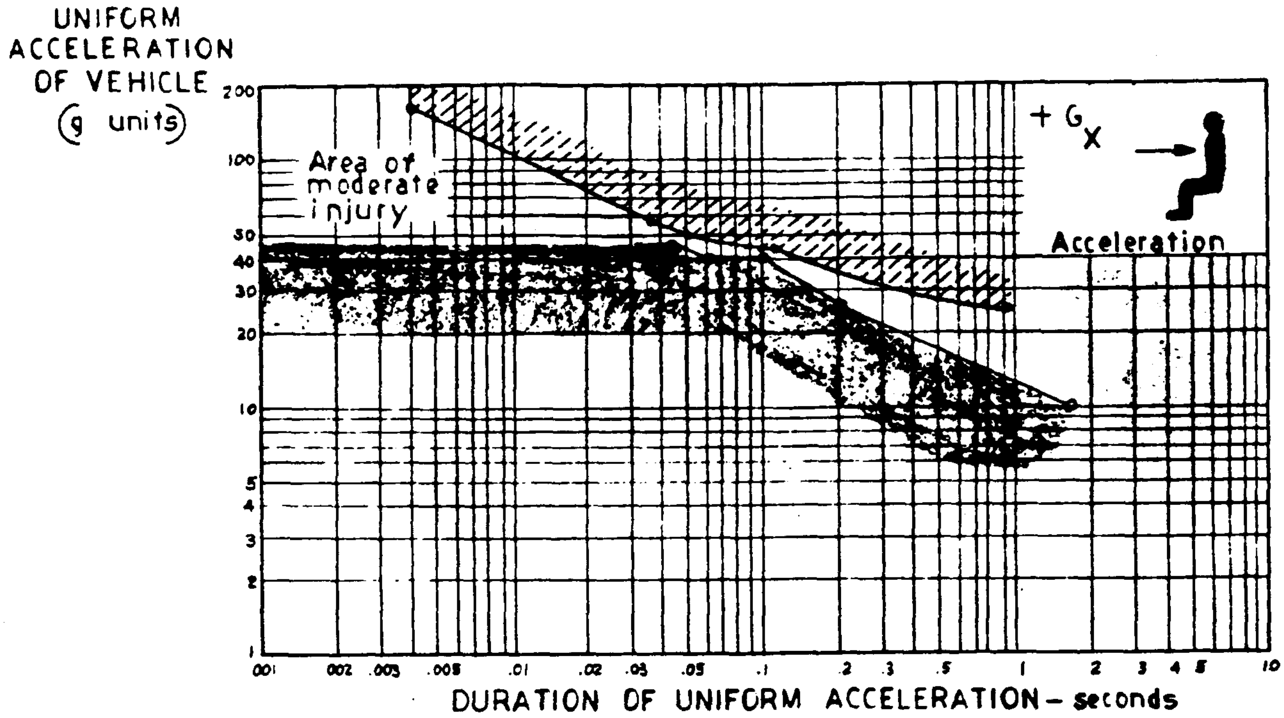


FIGURE 9-3

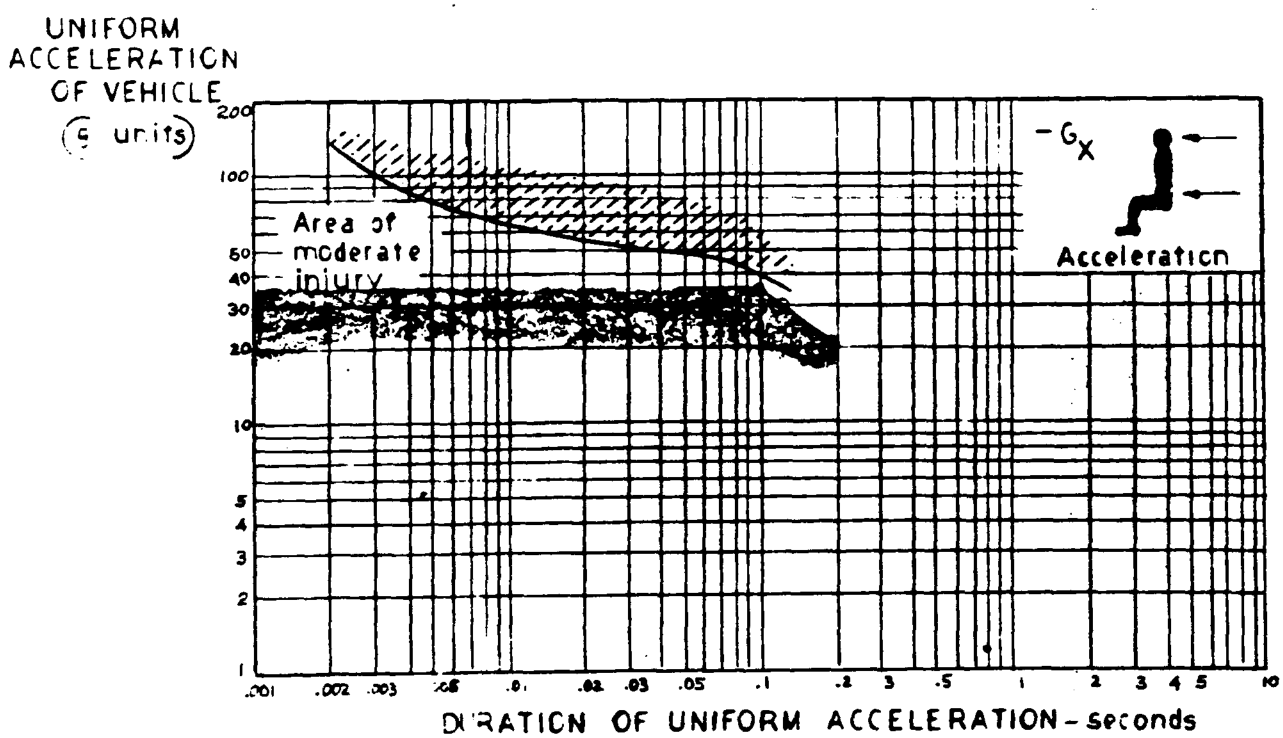
ABRUPT TRANSVERSE DECELERATIONS



A.

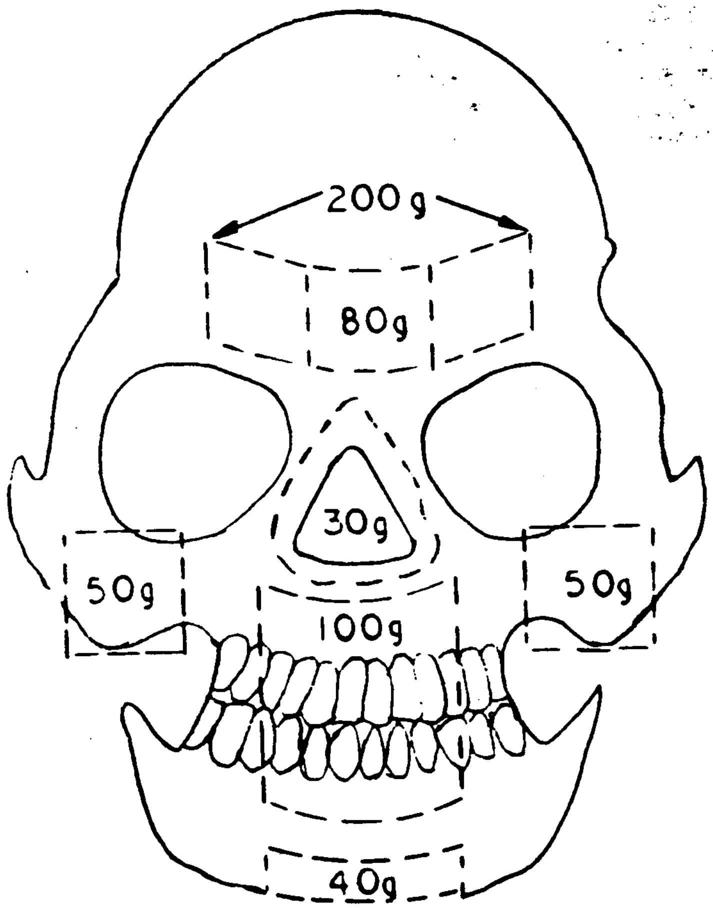
SEVERE INJURY

AREA OF UNINJURED



B.

FIGURE 9-4

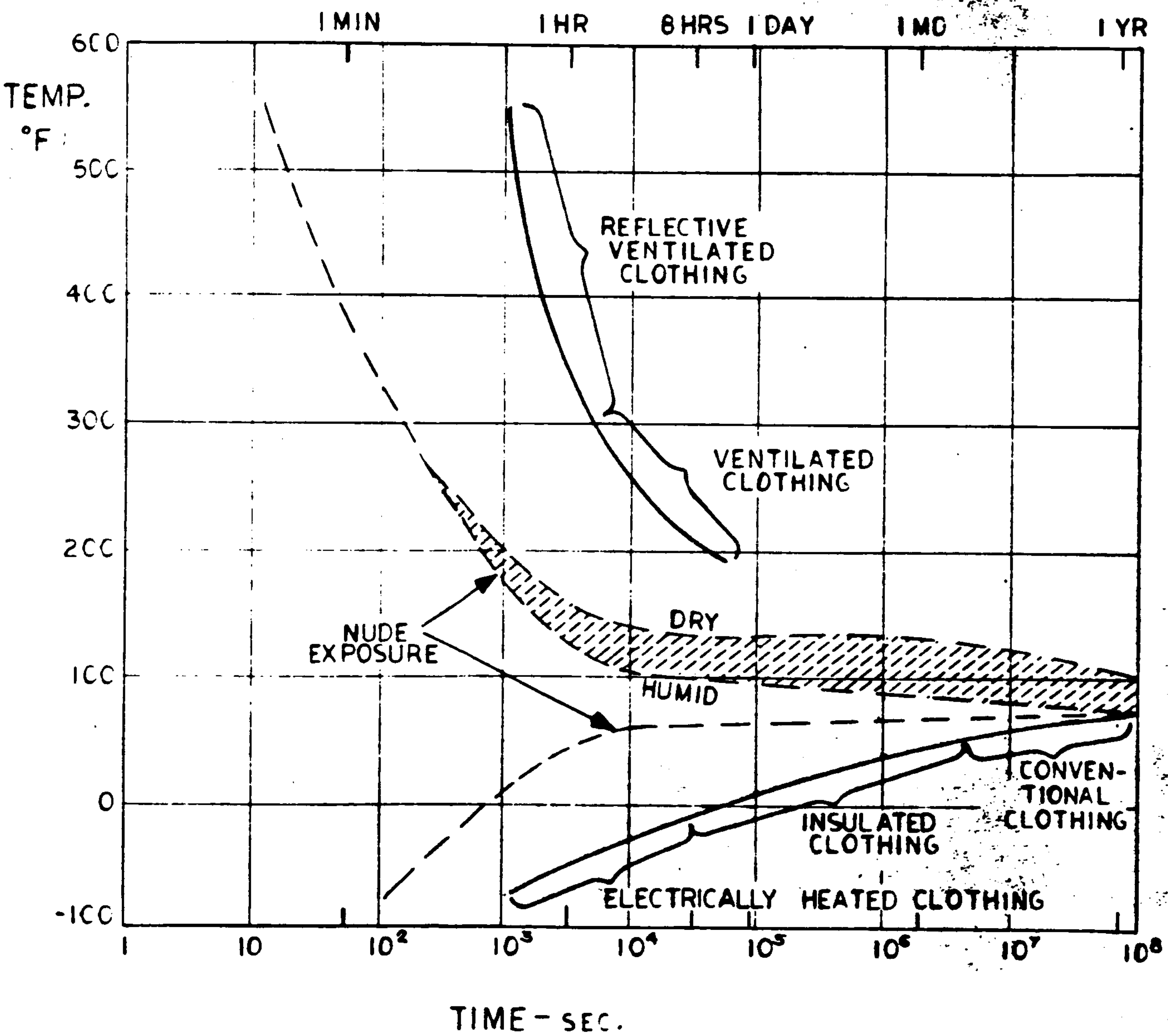


SUMMARY OF MAXIMUM TOLERABLE IMPACT FORCES ON A PADDED DEFORMABLE SURFACE

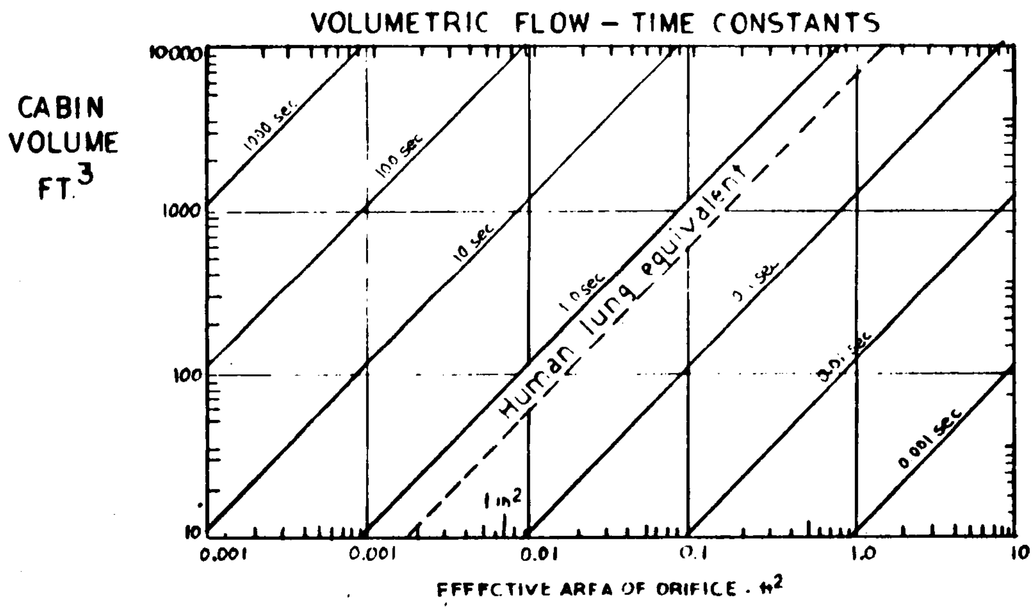
Ref. J. J. Swearingen AM-66-16
CIVIL AEROMEDICAL RESEARCH INSTITUTE
Office of Aviation Medicine
Federal Aviation Agency

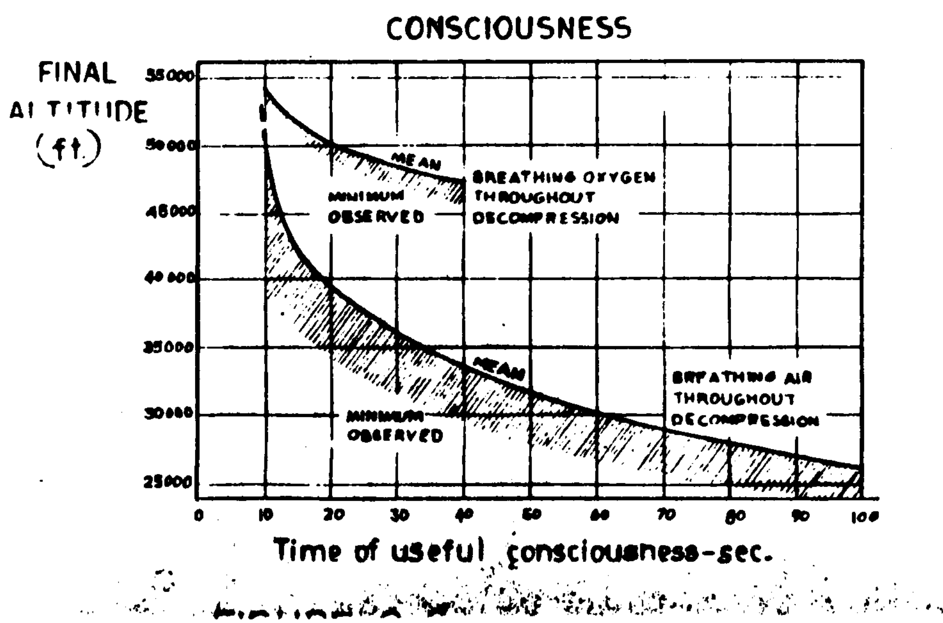
FIGURE 9-5

HUMAN TOLERANCE TO TEMPERATURE



DECOMPRESSION DATA





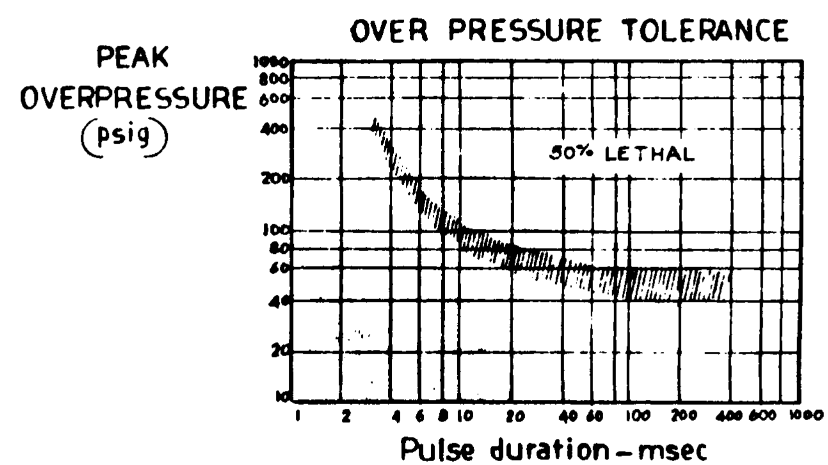


FIGURE 9-6

MECHANICAL EFFECTS OF HIGH DYNAMIC PRESSURES

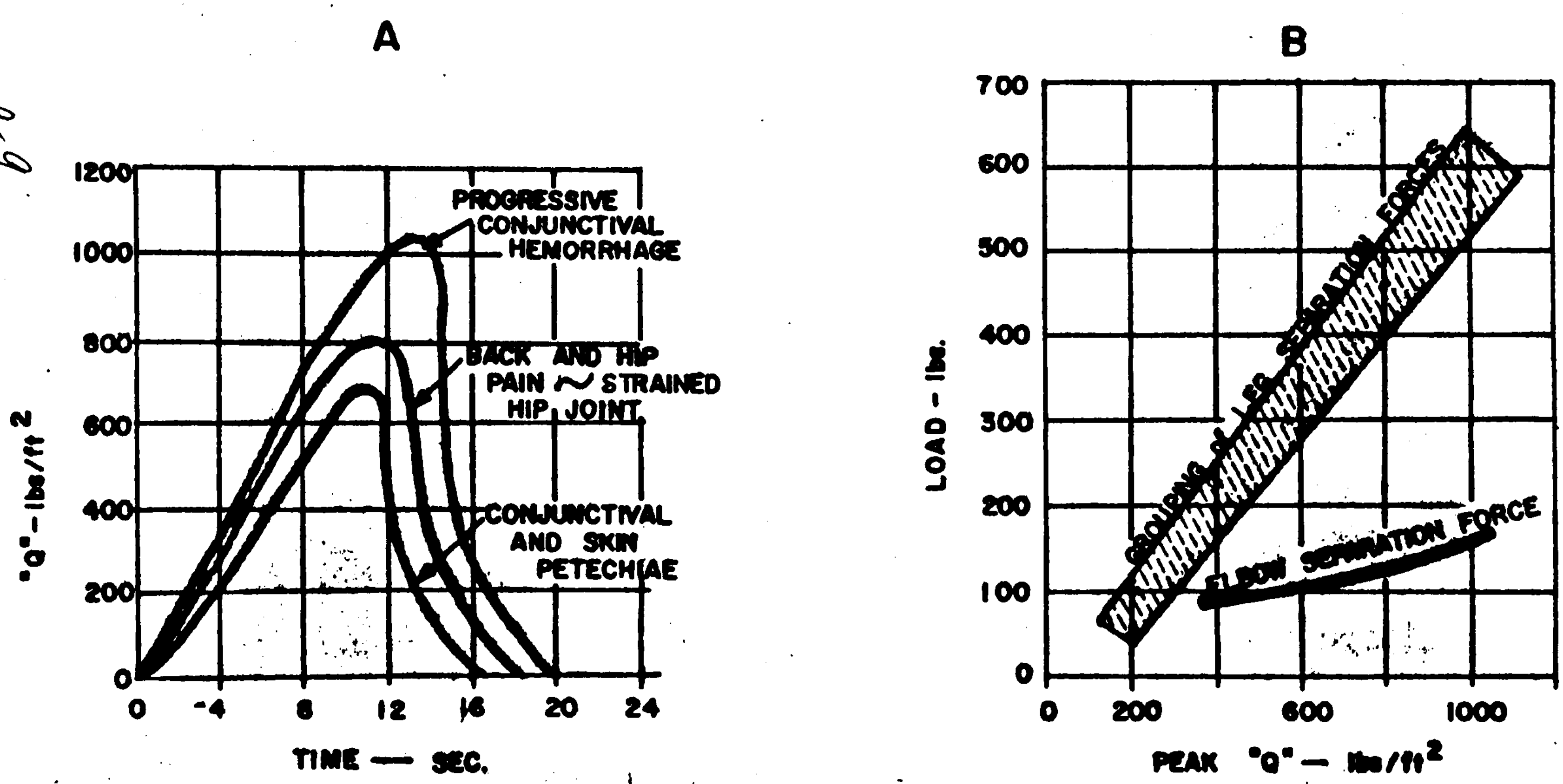


FIGURE 9-7

9-9

FIGURE 9-7

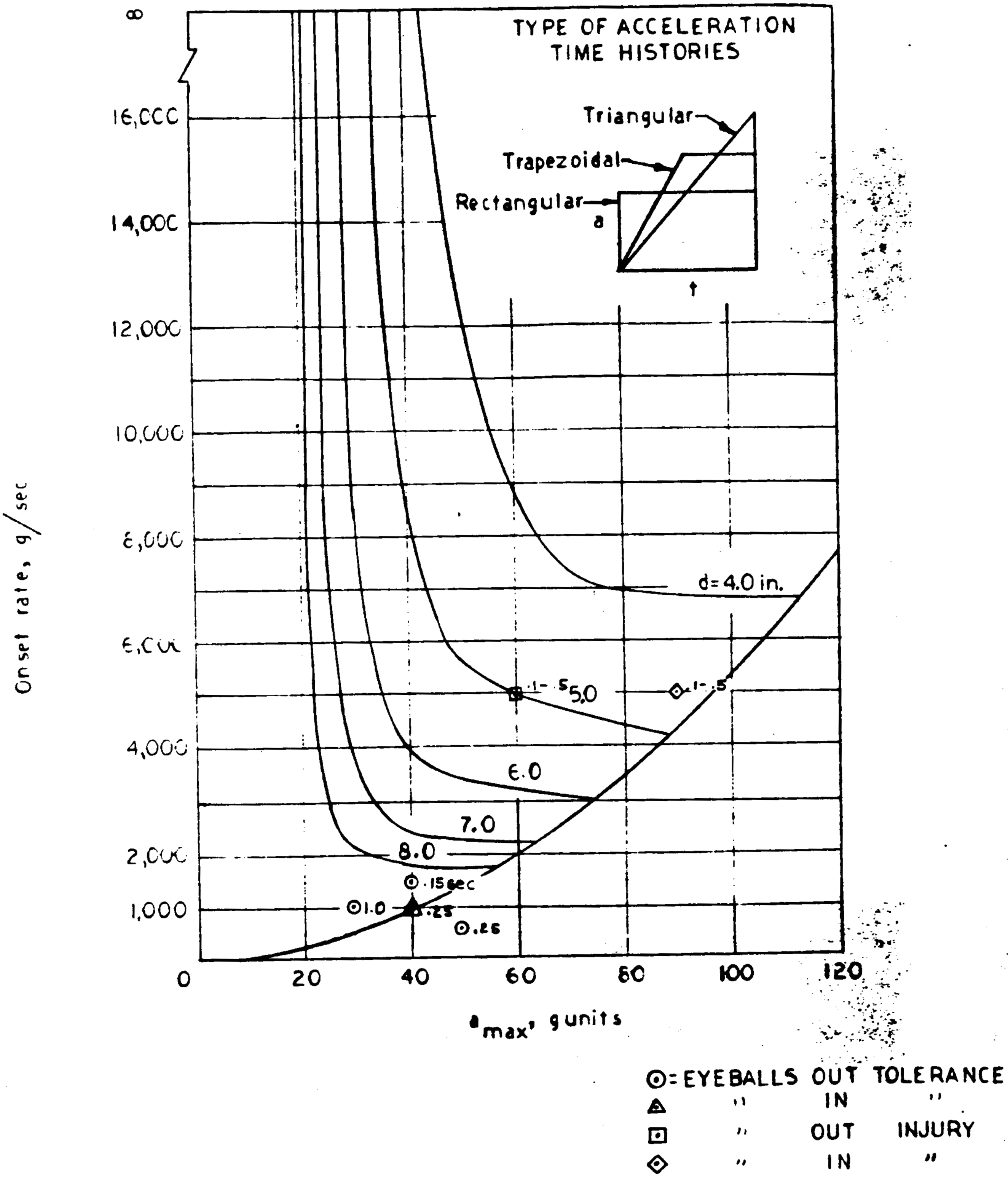


Figure 9-8 Variation of maximum acceleration and onset rate for constant values of stopping distance for an impact velocity of 30 ft/sec.

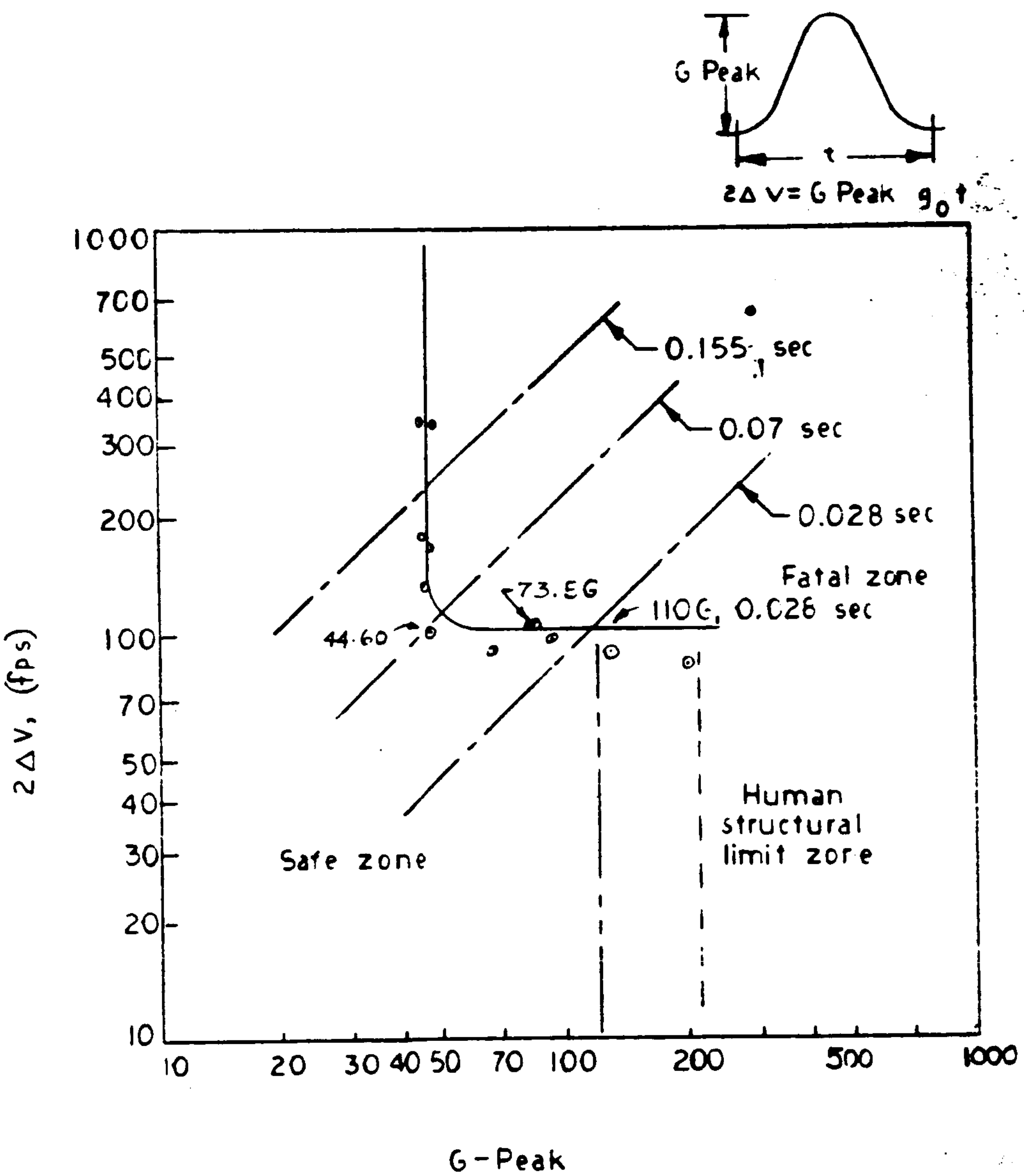


Figure 9-9 -Human Transverse Impact Tolerance, 2ΔV Versus Peak G

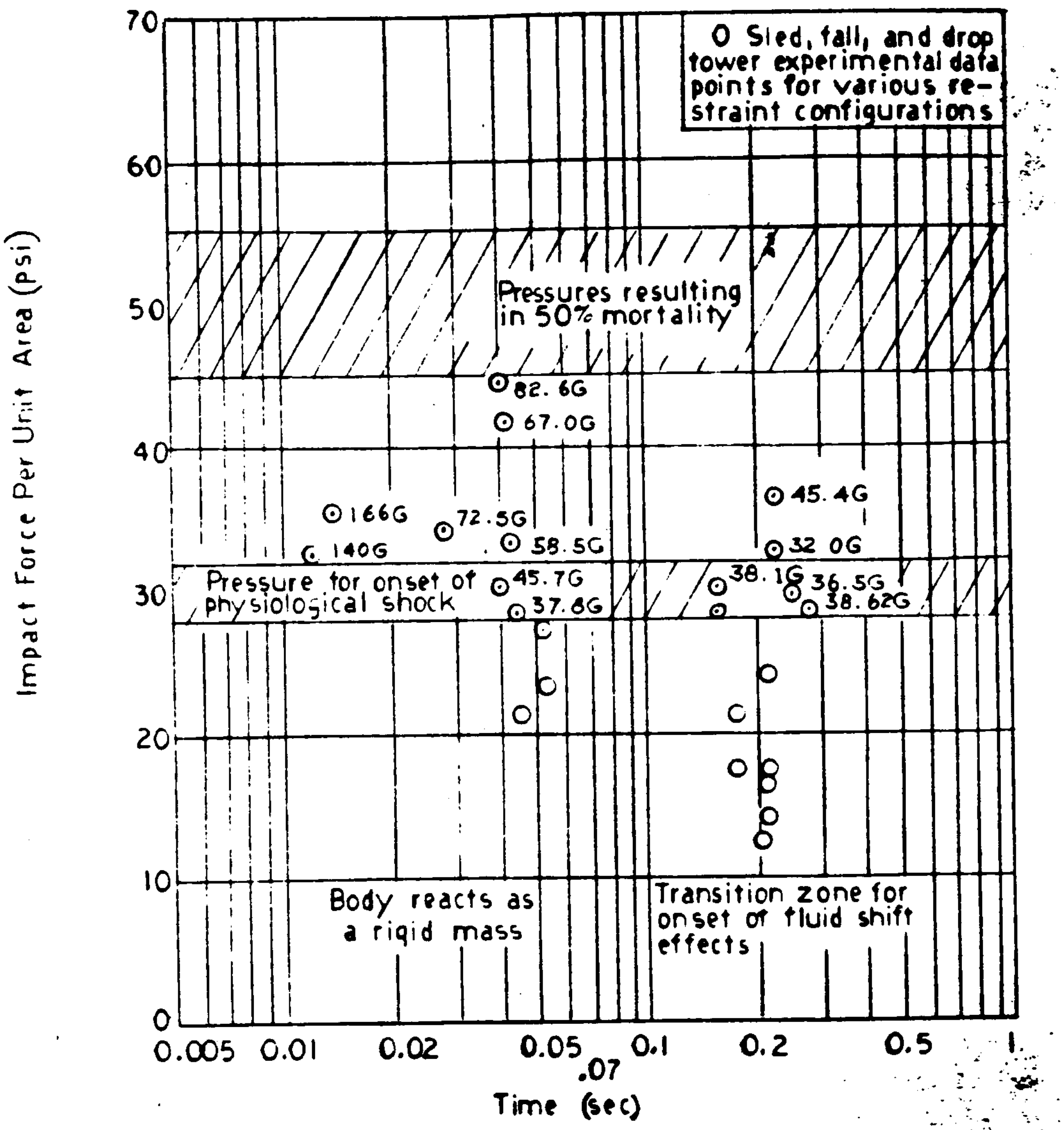


Figure 9-10 Human Transverse Impact Tolerance as Defined by Unit Impact Pressure and Time

REFERENCES

1. "Safety Considerations for Passengers and Crew"
   By: James E. Dougherty and Richard B. Stophlet
   Federal Aviation Agency, Washington, D. C.
   AIAA Third Annual Meeting
   Boston, Massachusetts, November 1966
   AIAA Paper Number 66-844

2. Civil Aeromedical Research Institute, Oklahoma City, Oklahoma
   Federal Aviation Agency, Office of Aviation Medicine

   2.1 Swearingen, John J.
   "Tolerances of the Human Face to Crash Impact"
   AM 65-20, July 1965

   2.2 Mohler, S. R. and Swearingen, J. J.
   "Cockpit Design for Impact Survival"
   AM 66-3, February 1966

   2.3 Swearingen, J. J., Hasbrook, A. H., Snyder, R. G.
   "Kinematic Behavior of the Human Body During Deceleration"
   AM 62-13, June 1962

   2.4 Swearingen, J. J.
   "Injury Potentials of Light Aircraft Instrument Panels"
   AM 66-12, April 1966

3. Flight Safety Foundation, Inc., Phoenix, Arizona

   3.1 "Full Scale Dynamic Crash Test of a Lockheed Constellation Model 1649 Aircraft" - Technical Report
   RPT. FAA-ADS-38 October, 1965
   By: Flight Safety Foundation
   Contract No. FA-WA-4569
   FAA Aircraft Development Service

   3.2 "Full Scale Dynamic Crash Test of a Douglas DC-7 Aircraft" - Technical Report
   RPT. FAA-ADS-37 April, 1965

References - Continued:

3. 3.3 Trecom Technical Report 66-77, January 1964
Experimental Research
"CH-21A Helicopter Airframe Deformation Under a Dynamic Crash Condition"
U. S. Army
Transportation Research Command
Ft. Eustis, Virginia

By: Flight Safety Foundation; W. H. Reed, D. F. Carroll; Contract DA 44-177-AMC-888(T)
J. L. Reed, Project Engineer
Lt. Col. T. C. Woodbury Johnson, Group Leader
Larry M. Hewin, Technical Director

4. Consolidated Notes on Aircraft Safety, J. J. Carroll; unpublished.

5. "Bioastronautics Data Book", NASA SP-3006

6. Scribner, Kimball J., Captain, Pan American Airways
"Emergency Barriers for Transport Aircraft"
Space and Flight Equipment Association Third National Flight Safety
Survival and Personnel Equipment Symposium, October 1965

7. Design of Passenger "Tie-Down", Sept. 1965, CSDM #1, Av-CIR-44-0-66, A. Howard Hasbrook, Aviation Crash Injury Research of Cornell University

8. "Janes, All the Worlds Aircraft, 1966-67", McGraw-Hill.

9. CAB Accident Investigation Report taken from Aviation Week and Space Technology, September 6, 1966, p. 113.

10. "Investigation of Crew Escape System Surface Impact Techniques For Advanced Aerospace Vehicles" ASD-TDR-63-173.

11. "Limited Investigation of Crushable Structures for Acceleration Protection of Occupants of Vehicles at Low Impact Speeds" NASA Technical Note D-158, October 1959.

12. "Energy Absorption Properties of Aluminum Honeycomb", Hexcel Products, Inc., TSB-110, Jan. 1, 1960.

APPENDIX A

AIRCRAFT DATA

MODEL	747	SST	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Passengers	490	350+	52	[illegible]	70-114	66-90	90-100	65-73
Empty Wt.Lb.	327,000	295,600	41,000	110,800	86,200	57,300	52,733	50,736
Gross Wt.Lb.	680,000	670,000	[illegible]	[illegible]	152,000	112,000	97,000	77,000
Landing Wt.	564,000	430,000	5[illegible],500	175,000	14[illegible],500	95,450	95,000	51,700
Max. Speed (M.P.H.)	540	......	......	600+	600	450	......	.84
Landing Speed (M.P.H.)	164	135	......	142	110	130	......	......
Fuel Capacity Gallons	50,320	......	......	14,830	7,680	5,520	4,670	5,513
Wingspan Ft.	195.6	180	93.7	130.[illegible]	108.0	90	93	93.4
Length Ft.	231.3	306	95.0	136.7	153.1	104.5	90.6	104.4
Wing Area Square Feet	5,500	9,220	263	2,440	1,650	1,300	......	925
Landing Field Length, Feet	6,800	6,800	4,450	6,200	4,610	4,260	5,000	5,020
Price FAF $	......	......	......	......	......	......	3,000,000	3,400,000
W/S	59.4	32.1	42.6	45.4	52.2	44.1	......	54.8
Lb./Pass Empty	667.3	844.6	788.5	671.5	885.7	608.8	585.9	676.5
$/Lb.	......	......	......	......	......	......	56.89	67.01

MODEL	810 Viscount	G-1159 Gulf-stream 2	340/440	1329-23E-99-F Jet Star	F-27	Jet Commander	Lear-23	Grand Commander
Passengers	70	39	52	10	44	7	9	11
Empty Wt.Lb.	41,565	32,000	31,300	20,000	25,000	9,155	6,350	5,200
Gross Wt.Lb.	72,500	56,000	48,000	42,500	40,000	16,800	12,500	8,500
Landing Wt.	64,000	51,430	47,650	35,000	37,500	16,000	11,800	8,500
Max Speed (M.P.H.)	357	.83	290	.82	314	.82	570	270
Landing Speed (M.P.H.)	140	118	95	140	91	112	98	82
Fuel Capacity Gallons	1,900I	3,180	......	2,660	1,000	926	847	223
Wingspan Ft.	93.5	68.9	105	54.4	95	43.3	35.5	49.5
Length Ft.	86	79.9	79	60.4	77	50.9	42	41.3
Wing Area Square Feet	963	793.5	964	543.0	754	303.3	231	255
Landing Field Length, Feet	......	3,500	......	5,220	1,340	3,900	1,400	1,450
Price FAF $	......	2,300,000	......	1,590,000	......	595,000	600,000	146,000
W/S	43.2	41.5	32.5	38.7	33.2	30.2	27.5	20.4
Lb./Pass Empty	593.8	1096.7	601.9	2000.0	568.2	1307.9	705.5	472.7
$/Lb.	......	69.91	......	75.72	......	64.99	94.49	28.25

MODEL	Beech Queen	Queen Air A-65	Aero Commander	PA-23-250 Aztec C	Super Skymaster	Cessna Super Skylane	V 35 Bonanza	Cessna 172
Passengers	7-9	9	7	6	4-6	6	4	4
Empty Wt.Lb.	4,640	4,890	4,700	2,933	2,615	1,795	1,941	1,300
Gross Wt.Lb.	7,700	7,700	7,500	5,200	4,300	3,600	3,400	2,400
Landing Wt.	7,350	7,350	7,500	5,200	4,200	3,600	3,400	2,400
Max. Speed (M.P.H.)	214	239	232	216	200	174	210	135
Landing Speed (M.P.H.)	80	80	74	68	63	61	63	52
Fuel Capacity Gallons	230	230	156	144	93	65	50	42
Wingspan Ft.	46	45.9	49.5	37.1	38.0	36.6	33.6	36
Length Ft.	33	35.5	35	30.2	29.7	28.2	26.4	26.5
Wing Area Square Feet	277	277	255	207.6	201	175	181	174
Landing Field Length, Feet	1,280	1,750	......	1,650	1,500	1,395	1,177	550
Price FAF $	125,000	......	......	55,000	42,500	23,995	32,500	13,000
W/S	16.8	17.7	18.4	14.2	13.0	10.3	10.7	7.5
Lb./Pass Empty	580.0	543.3	671.4	488.9	523.0	299.2	485.3	325.0
$/Lb.	26.94	......	......	19.00	16.25	13.37	16.74	10.00

MODEL	PA-28-180 Cherokee C	172	BD-1
Passengers	4	4	2
Empty Wt.Lb.	1,230	1,275	760
Gross Wt.Lb.	2,400	2,300	1,250
Landing Wt.	2,400	2,300	1,250
Max. Speed (M.P.H.)	152	138	145
Landing Speed (M.P.H.)	57	49	55
Fuel Capacity Gallons	50	42	24
Wingspan Ft.	30	36.2	24.6
Length Ft.	23.3	26.9	18.5
Wing Area Square Feet	160	174	98
Landing Field Length, Feet	1,150	1,250	400
Price FAF $	12,900	10,950	2,500
W/S	7.7	7.3	7.8
Lb./Pass Empty	307.5	318.8	380.0
$/Lb.	10.49	8.59	3.29